Volume 8, Number 5
September–October 2000

ISSN: 0869-5938

STRATIGRAPHY AND GEOLOGICAL CORRELATION

English Translation of *Stratigrafiya. Geologicheskaya Korrelyatsiya*

Editor-in-Chief
Boris S. Sokolov

http://www.maik.rssi.ru

Journal of the Fundamental and Applied Aspects of Stratigraphy and the Correlation of Geologic Events and Processes in Time and Space

МАИК "НАУКА/INTERPERIODICA" PUBLISHING

Stratigraphy and Geological Correlation

(Stratigrafiya. Geologicheskaya Korrelyatsiya)

ISSN: 0869-5938

Editor-in-Chief
Boris S. Sokolov
Member of the Russian Academy of Sciences,
Counsellor of the Presidium of the Russian Academy of Sciences (RAS)
Address for correspondence:
Staromonetnyi per. 22, Moscow, 109180 Russia
Phones: 7 (095) 951-2164; Fax: 7 (095) 233-5590.

Deputy Editor-in-Chief
Mikhail A. Semikhatov
Member of the Russian Academy of Sciences
Head of Laboratory, Geological Institute, RAS
E-mail: semikhatov@ginran.msk.su

Assistant Editor
Aleksei B. Herman
Senior Scientist,
Geological Institute, RAS
E-mail: herman@ginran.msk.su

EDITORIAL BOARD

Mikhail A. Akhmet'ev
Dr. Sci. (Geol.–Min.),
Head of Laboratory, Geological Institute, RAS
akhmetev@ginran.msk.su

Aleksandr S. Alekseev
Professor, Dr.Sci. (Geol.–Min.),
Department of Paleontology,
Moscow State University
aaleks@geol.msu.ru

Mikhail N. Alekseev
Dr. Sci. (Geol.–Min.),
Chief Scientist, Geological Institute, RAS
alekseev@ginran.msk.su

Ivan A. Basov
Dr. Sci. (Geol.–Min.), Laboratory Chief,
Institute of the Lithosphere, RAS
basov@ilsan.msk.ru

Michael G. Basset
Professor, National Museum of Wales,
Cardiff, UK

William A. Berggren
Professor, Department of Geology and Geophysics,
Woods Hole Oceanographic Institute, USA

Elena V. Bibikova
Dr. Sci. (Geol.–Min.), Chief Scientist,
Vernadsky Institute of Geochemistry
and Analytical Chemistry, RAS
sergei@bibikov.genebee.msu.su

Nikita A. Bogdanov
Corresponding Member of
RAS, Director, Institute of the Lithosphere, RAS
bogdanov@ilsan.msk.ru

Kiyotaka Chinzei
Professor, Institute of Geology,
University of Tokyo,
Tokyo, Japan

Nikolai M. Chumakov
Dr. Sci. (Geol.–Min.),
Chief Scientist, Geological Institute, RAS
chumakov@ginran.msk.su

Yurii B. Gladenkov
Dr. Sci. (Geol.–Min.),
Head of Laboratory, Geological Institute, RAS
gladenkov@ginran.msk.su

Mikhail A. Fedonkin
Corresponding Member of RAS, Laboratory Chief,
Paleontological Institute, RAS
mfedon@paleo.ru

Dmitrii L. Kaljo
Professor, Institute of Geology, Tallinn, Estonia

Kirilla I. Kuznetsova
Dr. Sci. (Geol.–Min.), Chief Scientist,
Geological Institute, RAS
kuznetsova@ginran.msk.ru

Victor E. Khain
Member of RAS, Chief Scientist,
Institute of the Lithosphere, RAS

Evgenii E. Musatov
Dr. Sci. (Geol.–Min.), Chief of St. Petersburg
Division, Institute of the Lithosphere, RAS
musatov@gocean.spl.su

Lidiya A. Nevesskaya
Dr. Sci. (Biol.), Laboratory Chief,
Institute of Paleontology, RAS
lenin33@paleo.ru

Aleksandr G. Ponomarenko
Dr. Sci. (Biol.), Chief Scientist,
Institute of Paleontology, RAS
vtopor@paleo.ru

Jurgen Remane
Professor, Institute de Géologie,
Université de Neuchâtel, Switzerland

Aleksei Yu. Rozanov
Corresponding Member of RAS,
Director, Institute of Paleontology, RAS
aroza@paleo.ru

Boris A. Sokolov
Corresponding Member of RAS, Professor, Dean,
Faculty of Geology, Moscow State University
mfedon@paleo.ru

Otto Walliser
Professor, Göttingen University, Göttingen,
Germany

Sun Weigo
Professor, Nanjing Institute of Geology
and Paleontology, Academia Sinica, China

Victor A. Zakharov
Dr. Sci. (Geol.–Min.), Head of Laboratory, Institute
of Geology, Geophysics, and Mineralogy, Siberian
Division, RAS, Novosibirsk

Aleksandr I. Zhamoida
Corresponding Member of RAS,
Russian Geological Institute, St. Petersburg

Staff Editor Tamara V. Trishkina

Editor of the English Translation Anatolii Ya. Sharas'kin, Dr. Sci. (Geol.–Min.)

SCOPE

Stratigraphy and Geological Correlation (*Stratigrafiya. Geologicheskaya Korrelyatsiya*) is the only journal in the world designed to provide comprehensive coverage of the fundamental and applied aspects of stratigraphy and the correlation of geological events and processes in time and space. Articles are based on the results of multidisciplinary research and are directed toward researchers, university professors, students, and geologists interested in understanding stratigraphy and the chronological features of the world's geological record.

Stratigraphy and Geological Correlation is abstracted and/or indexed in *Petroleum Abstracts*, *Research Alert*, *SciSearch*, *Current Contents* (*Physical*, *Chemical*, and *Earth Sciences*) and *World Translations Index*.

SUBSCRIPTION OFFICE
INTERPERIODICA
P.O. BOX 1831, BIRMINGHAM, AL 35201-1831 USA
PHONE: (800) 633-4931; (205) 995-1567 (outside US and Canada)
FAX: (205) 995-1588

PUBLISHER
INTERNATIONAL ACADEMIC PUBLISHING
COMPANY "NAUKA/INTERPERIODICA"
PROFSOYUZNAYA UL. 90, MOSCOW, 117864 RUSSIA
PHONE: 7 (095) 336-1600; FAX: 7 (095) 336-0666
E-mail: compmg@maik.rssi.ru
Web Site: http://www.maik.rssi. ru

SUBSCRIPTION PRICES (2000, Volume 8, 6 issues)
US $980.00 (North America), $1125.00 (elsewhere). A 5% discount is given on 2-year orders. Subscriptions may be entered at any time. Orders may be placed at agencies or directly. There is a 5% discount to all subscription agencies. Cancellations not allowed except for duplicate payment. Prepayment required. Advance payment required in US$/US bank. MasterCard/Visa accepted. Make checks payable to *Stratigraphy and Geological Correlation* or Interperiodica.

Stratigraphy and Geological Correlation (ISSN: 0869-5938) is published bimonthly for US $980.00 (North America), outside North America for $1125.00 per year by MAIK "Nauka/Interperiodica", 5724 Hwy. 280 East, Birmingham, Alabama 35242-5724 USA. Periodical postage paid at Birmingham, Alabama, and additional mailing offices. POSTMASTER: Send address changes to *Stratigraphy and Geological Correlation*, P.O. Box 1831, Birmingham, Alabama 35201 USA.

The journal was founded in 1993.
Original Russian Edition Copyright © 2000 by the Russian Academy of Sciences
and Division of Geology, Geophysics, Geochemistry, and Mining Sciences, RAS.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).
Printed in the USA by Pleiades Publishing, Inc.

Contents

Vol. 8, No. 5, 2000

Simultaneous English language translation of the journal is available from MAIK "Nauka/Interperiodica" (Russia).
Stratigraphy and Geological Correlation ISSN 0869-5938.

Significance of Microfossils for Riphean Stratigraphy of the Southern Urals (Bashkirian Meganticlinorium) and Adjacent Region (Kama–Belaya Aulacogen)
A. F. Veis, N. N. Larionov, N. G. Vorob'eva, and Lee Seong-Joo 423

Fusulinid-Based Zonation of the Melekhov Horizon (Upper Carboniferous, Gzhelian Stage) in the Perm' Region
A. P. Vilesov 447

Biogeographic Zoning of the Indian Ocean in the Late Mesozoic
E. V. Ivanova 461

The Albian–Cenomanian Boundary in the Southwestern Crimea
T. N. Gorbachik, L. F. Kopaevich, and D. P. Naidin 470

Palynological Characteristics of Cenozoic Coal-Bearing Deposits, the Snezhnogorskii Locality in the Verkhnyaya Zeya Basin
T. V. Kezina and G. F. Ol'kin 482

Pleistocene Climatic Events in the Geological History of the Black Sea
P. V. Fedorov 491

New Data on the Paleolithic Geochronology in Southern Levant
S. A. Laukhin, A. Ronen, V. A. Ranov, G. A. Pospelova, Ya. M. Burdukevich, Z. V. Sharonova, V. A. Volgina, O. A. Kulikov, V. K. Vlasov, and A. Tsatskin 498

Angular Unconformities in the Turkestan–Alai Region and Correlated Geological Events of the Carboniferous Time
V. I. Belousov 511

Personalia

Nikolai Lazarevich Bublichenko (1899–1999): A Centenary from the Hour of His Nativity 526

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 423–446. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 3–28.
Original Russian Text Copyright © 2000 by Veis, Larionov, Vorob'eva, Lee Seong-Joo.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Significance of Microfossils for Riphean Stratigraphy of the Southern Urals (Bashkirian Meganticlinorium) and Adjacent Region (Kama–Belaya Aulacogen)

A. F. Veis*, N. N. Larionov, N. G. Vorob'eva*, and Lee Seong-Joo*****

** Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia*
*** OAO "Bashkirgeologiya", ul. Rikharda Zorge 9/1, Ufa, 450059 Bashkortostan, Russia*
**** Geological Faculty, Kyungpook National University, Taegu, 702-701 South Korea*

Received July 29, 1999

Abstract—Taxonomic composition of six stratigraphically important Riphean microbiotas from the southern Urals (Bashkirian meganticlinorium) and adjacent region (the Verkhnyaya Kama depression of the Kama–Belaya aulacogen) is considered. Microbiotas characterize the Kuzha (two microbiotas), Tyul'men, Nugush, and Lemeza sequences of the Riphean stratotype and the Kyrpy Group (Pal'niki microbiota) of the eastern Russian plate. Stratigraphic interpretation of these deposits (except the Nugush and Lemeza sequences) is still ambiguous. The Kuzha and Tyul'men sequences are considered either as diachronous and belonging to different horizons of the upper part of the Middle Riphean Yurmatinian Group, or as synchronous and corresponding to the long-lasting pre-Karatavian hiatus. The Kyrpy Group of the Urals region is referred to the Lower Riphean, although some researchers correlate it with the Karatavian. The examined microbiotas (first of all, the Kyrpy and Nugush ones) consist of abundant and diverse (more than 20 genera and 25 species) microfossils including those of the intricate structure. The new data obtained elucidate the structure of the Yurmatinian–Karatavian interval of the Riphean and the age of the Kyrpy Group of the Urals region, being useful for the distant interregional correlation.

Key words: *microbiotas, stratotype, microfossil assemblage, microphytological levels, correlation*

INTRODUCTION

In recent years, differences between the Upper Proterozoic and Phanerozoic general scales became greater despite the efforts of many researchers to make closer the principles and methods of their elaboration (Semikhatov *et al.*, 1991; *Postanovlenie...*, 1993). Taking into consideration that scientists advocating the priority of the Riphean are adherents of chronostratigraphic interpretation, it is clear that these differences are completely or to a great extent caused by an abstract chronometric concept popular amid specialists in the Precambrian geology and embodied in the Paleoproterozoic, Mesoproterozoic, and Neoproterozoic scale proposed as an alternative to usual stratigraphic scale about ten years ago by the International Subcommission on the Precambrian Stratigraphy and approved by the IUGS (Plumb, 1991; for review see Semikhatov, 1993, 1995, 1997). That scale leans upon one of the concepts (substantial) of physical time that is formally brought into geology to be considered as a "pure" time coordinate independent of the concrete content of its subdivisions, i.e., of representative supracrustal rock successions.

A fast expansion of this abstract chronometric concept willy-nilly with a help of some Russian researchers, culminates in two negative consequences, which cannot be reckoned reasonable. First, this can result in elimination of the Riphean now accepted to be one of general Precambrian units. Second, this may discard the Riphean chronostratigraphy, which demonstrated its high heuristic level and deals with a real geological time recorded in successions of sedimentary rocks bearing organic remains. The situation is aggravated by contradicting views on the Riphean scale: some researchers believe that the Riphean records are completely deciphered except for some events of secondary importance, whereas others believe that the Riphean represents just about a fiction. The uncertainty is unavoidable, since there are ideas to consider the Riphean stratotype structure as a tectonic triplex, to regard strontium isotope ratios in carbonate rocks from the "pre-Riphean" reference sections of Siberia as extra low, and to interpret age of representative Riphean microbiotas on the basis of isotopic–geochronological data only discarding the contradicting paleontological evidences, etc.

In this connection, the regional investigations elucidating the real geological and paleobiological contents of the Riphean are of particular importance. One of the main objects suitable for this is the Riphean stratotype of the southern Urals. Most important stratigraphic

problems concern the microphytological characteristics of the stratotype and the structure of deposits transitional between the Yurmatinian and Karatau groups, which are traditionally considered as type successions for the Middle and Upper Riphean, respectively (Schatsky, 1945; *Stratigrafiya...*, 1963; *Stratotip...*, 1983; Keller *et al.*, 1984; Semikhatov *et al.*, 1991; *Postanovlenie...*, 1993; Kozlov *et al.*, 1997; and others). In 1996–1997, we studied organic-walled microfossils from the Yurmatinian–Karatavian boundary deposits in the Bashkirian meganticlinorium (Tyul'men, Kuzha, Nugush, and Lemeza sequences), as well as microfossils from Riphean sections of the subplatform type in the Urals region. The study provided principally new data on microphytological characteristic of six, variable in diversity microbiotas from the above-mentioned deposits. The microbiotas consist of dozens of microfossil genera and species, the large forms of intricate structure included. Most diverse are the Pal'niki (Kyrpy) microbiota from the Urals region and the Nugush microbiota of the Bashkirian meganticlinorium, whereas the Tyul'men, Kuzha, and, particularly, Lemeza microbiotas are less representative.

Stratigraphic units bearing the above-mentioned microbiotas occupy different position in the modern regional schemes; most certain amid them are positions of the Nugush and Lemeza biotas from synonymous subformations of the Zil'merdak Formation, the basal one in the Karatau Group, which, as was mentioned, represents a type section of the Upper Riphean. According to dominant views, the Kuzha and Tyul'men deposits belong to the Yurmatinian Group, whereas according to others opinions, they correspond to a presumable long-lasting pre-Karatavian hiatus. Most researchers correlate the Kyrpy Group of the Urals region with the Lower Riphean Burzyan Group, although there are opinions that it is a unit of the Karatavian. In the light of these contradictions, new data on microphytological characteristic of the mentioned Precambrian subdivisions of the southern Urals and adjacent region, which are considered below, seem particularly crucial. Integration of newly obtained and previously published data into the general vertical succession of microfossils in the Yurmatinian–Karatavian boundary deposits allows us to demonstrate once more the role of paleontological evidences in substantiation of the Middle–Upper Riphean boundary.

STRATIGRAPHIC AND GEOGRAPHIC POSITIONS OF STUDIED MICROBIOTAS

General characteristics of studied sequences. Among three stratigraphic units: the Burzyan, Yurmatinian, and Karatau groups composing, as is traditionally thought, the Riphean type section of the Urals, the first one is excluded from consideration, because new microphytological data have not been obtained from this level. Deposits of the Yurmatinian Group will be characterized only by example of the Tyul'men succession that is most frequently referred to the upper part of the clayey–calcareous Avzyan Formation topmost in the Middle Riphean section. Making our choice, we took into account that the lower two units of the Yurmatinian Group, namely, the substantially volcanogenic Mashak and mostly sandy Zigal'ga formations are promising almost nothing in respect of the microphytological remains because of their lithology, whereas the revision of sandy–clayey rock samples characterizing the Zigaza–Komarovo Formation and a larger part of the Avzyan Formation showed that microfossils detectable here are similar to those described previously (Yankauskas, 1982; Veis *et al.*, 1990; Mikhailova and Podkovyrov, 1992). As for the Karatau Group consisting of six units, we will consider only microfossils from its Zil'merdak Formation. New data obtained from the overlying part of the group (interval of the Katav, Inzer, Min'yar, Uk, and Krivaya Luka formations) will be discussed in the next article.

Thus, the microphytological data considered below characterize four separate intervals of the Riphean section studied in different areas of the southern Urals (Bashkirian meganticlinorium) and Volga–Urals region (the Verkhnyaya Kama depression of the Kama–Belaya aulacogen, Fig. 1). Three of these intervals belong to the Yurmatinian–Karatavian succession of the Riphean stratotype in the southern Urals. The so-called Kuzha Group corresponding to the first interval is locally known in the stratotype area and corresponds, in opinion of some Uralian geologists, to a hiatus between the Middle Riphean Yurmatinian and Upper Riphean Karatau groups of the adjacent areas (Filippov, 1997; and references therein). In opinion of other researchers, this unit is a stratigraphic analogue of the Zigaza–Komarovo and/or Avzyan formations (*Stratotip rifeya...*, 1983; Larionov, 1994; Maslov, 1997; Kozlov *et al.*, 1997; and others). Filippov (1997), who analyzed many borehole sections of the group in the southern part of the region (Kuzha syncline of the Yamantau anticlinorium), divided it into the local sandy–silty Tukaevo (here termed as Nizhnyaya Kuzha), clayey–dolomitic Urtino, rhythmical terrigenous–carbonate Biktimir, and substantially carbonate Bretyak formations.[1] The identified microfossils characterize the Nizhnyaya Kuzha and Urtino formations. To keep the strict stratigraphic and geographic allocation, we consider further precisely these subdivisions of the Kuzha Group (with due account for the aforementioned reservation) despite different views of co-authors and other geologists on the validity of the group proper and its subordinate lithostratigraphic units. The second interval corresponds to the Tyul'men Beds (Subformation), which are usually considered as representing the terminal

[1] The Tukaevo Formation mainly composed of gray sandstones and siltstones was originally distinguished in the Riphean section of the Volga–Urals region (*Stratigraficheskii slovar'...*, 1994, p. 259). According to stratigraphic regulations, its name cannot be used within the Bashkirian meganticlinorium representing another structural region.

member of the Avzyan Formation of the Yurmatinian Group (Kozlov, 1982; Kozlov *et al.*, 1997; Maslov, 1997), although sometimes they have been referred to the Kuzha Group (Filippov, 1997). The beds were most completely penetrated in some boreholes drilled at the eastern limb of the Inzer synclinorium. The third interval is represented by the Nugush and Lemeza subformations of the Karatavian Zil'merdak Formation. Their microfossils are sampled from natural exposures in the western part of the Inzer synclinorium (*Stratotip rifeya...*, 1983).

The next, fourth interval that has been sampled beyond the southern Urals stratotype area corresponds to the Kyrpy Group of the Volga–Urals region, the lowest one of three groups (Kyrpy, Serafimovka, and Abdulino) defined now in the Riphean deposits of that region (Ozhiganova, 1983; Kozlov *et al.*, 1997, 1998; Maslov and Isherskaya, 1998; and others). This interval is recovered by recently drilled Borehole Azino–Pal'niki-133 in southern Udmurtiya (Kozlov *et al.*, 1998). The studied microfossils exemplify the dolomitic–clayey Kaltasy Formation, the second unit in the group section, where it is underlain by the substantially sandy Prikamskii Formation and overlain by the sandy–silty Nadezhdino Formation. Brief lithological characteristics of all intervals and a review of available views of their stratigraphic position are considered below.

The Bashkirian meganticlinorium. In this structural region, microfossils were examined in rock samples from the Nugush and Lemeza subformations of the Zil'merdak Formation, the basal one in the Karatau Group, from the Tyul'men Formation, and from the so-called Kuzha Group. The Nugush and Lemeza successions correspond to the middle part of the Zil'merdak Formation. In the examined sections of the Inzer synclinorium, they overlie the Bir'yan sandstones, which are separated by an unexposed interval from the underlying deposits of the Avzyan Formation and grade upward into the clayey Bederysh Subformation underlying the Karatau Group succession. Examined samples (18 and 15 samples from the Nugush and Lemeza units, respectively) were collected in excavations of the Beloretsk–Ufa road running along the Malyi Inzer River valley and in the vicinity of the Inzer Settlement, where exposed sections of both units are most complete as compared to others in the Inzer synclinorium. In the above exposures, the Nugush Subformation (200–210 m) is composed of gray and green siltstones and shales. The sampled interval of the subformation (about 50 m) is located 6 km west of the Inzer Settlement and corresponds mainly to its upper half. The Lemeza Subformation (more than 150 m thick) is represented here by light-colored sandstones with rare interbeds of dark shales. Examined samples characterize the upper 30-m-thick interval of its section exposed 2 km east of the Inzer Settlement (Fig. 1).

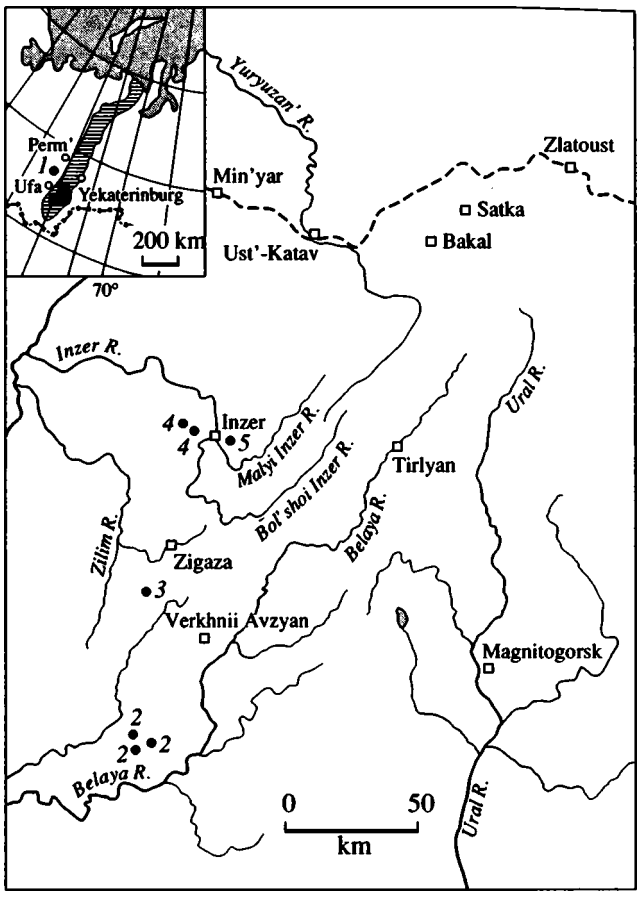


Fig. 1. Studied localities of microbiotas in the southern Urals and adjacent region: (*1*) Kyrpy (Pal'niki); (*2*) Kuzha (Nizhnyaya Kuzha and Urtino); (*3*) Tyul'men; (*4*) Nugush; (*5*) Lemeza.

Age constraints for two other examined intervals, namely of the Tyul'men and Nizhnyaya Kuzha–Urtino successions, are uncertain because of the ambiguous interpretation of the Yurmatinian–Karatavian boundary succession in the Riphean stratotype. At present, there are three versions of their structural relations: (1) the transition between the intervals is gradual, at least in some areas (Kozlov *et al.*, 1997; and others); (2) they are separated everywhere by a hiatus, although indications of the latter are unknown (Maslov, 1997; Shalaginov and Maslov, 1997); and (3) the successions are locally separated by the Kuzha Group (Filippov, 1997).

The problem concerning the stratigraphic individualization of Kuzha deposits and their position in the Uralian type succession of the Riphean (compare: Filippov, 1997; Kozlov *et al.*, 1997; Maslov, 1997; and others) is born by different age interpretation of peculiar rock facies composing a large narrow block stretching in the southern part of the Bashkirian meganticlinorium from the Zigaza Settlement in the north to the abandoned Kuzha Settlement in the south. The block is mapped as the tectonically isolated structure of subme-

ridional orientation more than 80 km long and 7 to 15 km wide. The visible section of the block is about 3.5 km thick and includes the presumably Lower Riphean Kurgas Complex of black shales (over 1500 m thick) and unconformably (probably, with the weathering crust at the base) overlying Kuzha Group (over 2000 m thick). Adherents of an autonomous status of the Kuzha Group include into the latter also the Nizhnyaya Kuzha Formation (see above) composed of gray and rose sandstones and dark siltstones (380–400 m), Urtino Formation of quartzite-like sandstones grading into light dolomites and lilac shales (400–420 m), Biktimir Formation of gray and variegated rhythmites and sandstones (1200 m), and Bretyak Formation of white porous dolomites displaying affinity with evaporites and associated with red shales (220 m). As shown by detailed studies, boundaries of the considered block with deposits of the Burzyan, Yurmatinian, and Karatau groups correspond to suture zones with relevant signs of magmatism, thermal metamorphism and ore mineralization (Filippov, 1997).

The individuality of the Kuzha Group is substantiated, in addition to its specific lithology, by peculiar features of associated ore occurrences that have no analogues in other groups of sediments known in the southern Urals, as well as by rare paleontological finds. The latter include rare Late Riphean microphytoliths (Filippov, 1997, with reference to data of Z.A. Zhuravleva) and scarce microfossils detected by Yankauskas (1982) in the Tukaevo (i.e., in the probable analogue of the Nizhnyaya Kuzha Formation) and underlying Kabakovo deposits in the Bashkirian sector of the Urals region, where they were penetrated by Borehole Kabakovo-62. In this connection, it should be noted that Yankauskas repeatedly emphasized the post-Yurmatinian appearance of Tukaevo microfossils (see also Andreev *et al.*, 1981).

According to published data, the Tyul'men deposits described as an autonomous lithostratigraphic unit (beds, subformation, etc.) in some publications (Kozlov, 1982, 1986; and others) represent a tectonic melange of the Kuzha rocks different in age that is exposed in the type section along the Tyul'ma River 60 km northeast of the Zigaza Settlement (Filippov, 1997). This melange originated in the thrust zone about 200 m wide located between exposures of the Yurmatinian and Karatau groups, where it is composed of large blocks (10–50 m across) of presumable Kuzha dolomites, siltstones, and sandstones intruded by diabase dikes.

The majority of Uralian geologists (*Stratotip...*, 1983; Larionov, 1994; Kozlov *et al.*, 1997; Maslov, 1997; Shalaginov and Maslov, 1997; and references therein) express absolutely different views on stratigraphic position and relationship of the Kuzha and Tyul'men successions. According to some of them, the Kuzha deposits of peculiar lithology are correlative with the Avzyan or, more exactly, with the lower–middle Avzyan (Kataskin–Ushakovka) deposits and, partly, with the Zigaza–Komarovo (Seregino–Tukan), or even with the Zigal'ga successions. Moreover, emphasizing apparent differences in lithology, mineral composition, and ore mineralization between the Kuzha and Avzyan (more exactly, between the Zigaza–Komarovo and Avzyan) rocks and pointing to specific attitude of both units at their contact (relatively gentle subhorizontal dipping of the former and steep to very steep dip angles characterizing the latter), the cited authors believe that we deal, in fact, with successions concurrent in age, but sharply different in lithology. The Kuzha deposits are interpreted as accumulated mainly in the coastal shallow marine setting, whereas the Avzyan rocks are attributed to distal sediments of relatively deeper settings. It should be noted that according to the large-scale geological mapping, the Kuzha rocks have, as a rule, an autochthonous position in modern structure of the Bashkirian meganticlinorium, whereas outcrops of the Avzyan rocks are known in the substantially deformed allochthonous blocks. The proposed correlation is indirectly supported by similar paleomagnetic properties of characteristic Avzyan and Kuzha rocks, by regular changes in their metallogeny (transition from Ba-polymetallic to Ba–Mg and then to Ba–Mg–Fe mineralization by passing from western to central and then to eastern parts of the region), and also by some structural features (Mikhailov, 1983; Larionov, 1994; Kozlov *et al.*, 1997; and others).

Simultaneously, scientists, who correlate the Zigaza–Komarovo and Avzyan successions with the Kuzha deposits, are antagonists by positioning the Tyul'men succession in the Riphean section of the southern Urals. Evaluating in different manner the correlative potential of specific lithological features typical of the Tyul'men beds and their sporadic manifestations within the Avzyan Formation, some geologists place the beds at the top of the latter (*Stratotip...*, 1983; Kozlov *et al.*, 1997; Maslov, 1997), whereas others believe that the Kutkurskii (middle Avzyan) and/or even lower strata of the formation erroneously referred to the Tyul'men Subformation in some key sections, for instance, in that of Borehole 26, where microphytological remains are well studied (Larionov, 1994; and others). We should remember here that, according to data of T.V. Yankauskas, E.V. Kozlova, and A.F. Veis, the Tyul'men assemblage of microfossils from the Borehole 26, except for its transitional taxa, differs greatly from the Avzyan assemblages (silicified representatives included), being comparable in morphology and preservation degree of organic remains only with those of the Lower Karatavian (Yankauskas *et al.*, 1989; Veis *et al.*, 1990; Kozlova, 1993, and others). The stratigraphic significance of Kuzha and Tyul'men microfossil assemblages will be discussed below after presentation of new materials.

Samples from the Kuzha Formation (68 in total) were collected in the southern part of its distribution area from cores of 23 boreholes drilled in the vicinity

of the abandoned Kuzha Settlement and from natural exposures in the Kuzha River valley. In this representative collection, identifiable microfossils are present only in 13 samples from 3 boreholes: (1) in 3 and 4 samples respectively characterizing intervals of 190–177 m and 153–140 m, which correspond in Borehole 150 to the shale–siltstone beds of the Nizhnyaya Kuzha Formation; (2) in 4 samples from the interval of 130–120 m of Borehole 158, which represent the lower variegated shales and siltstones of the Urtino Formation; and (3) in 2 samples from the interval of 294–282 m of Borehole 180, where dolomites with shale interbeds correspond to higher strata of the same formation. The Tyul'men assemblage of microfossils was recognized as well in 10 of 25 samples collected from dark gray shales penetrated in the interval of 225–54 m by Borehole 26 near the Ismakaevo Settlement. This borehole is located at northern continuation of the Kuzha syncline (on its western limb) 3 km southeast of the Nizhnie Saryshki Village.

The Volga–Urals region. The Kyrpy assemblages of microfossils from this region were examined in samples collected by V.I. Kozlov from cores of Borehole Azino–Pal'niki-133 and kindly donated for our study. The borehole was drilled at the area apex of the local arch structure located within the Verkhnyaya Kama depression of the Kama–Belaya aulacogen 40 km southeast of Izhevsk (Kozlov *et al.*, 1998). Most samples (23 of 26 examined samples turned out to be with microfossils) were collected from the upper, substantially carbonate complex (interval of 3350–2024 m) distinguished in geological profiles of Riphean deposits in the region. Additional two samples barren of microfossils were collected near the top of the underlying carbonate–terrigenous complex (interval of 4204–3350 m).

In their bed succession, petrochemical and magnitometric characteristics, deposits recovered by Borehole Azino–Pal'niki-133 (interval of 4204–2024 m) are almost identical to those penetrated by Borehole Arlan-7000 (interval of 4550–1910 m) drilled in northwestern Bashkortostan. The last borehole section is accepted for stratotype of the Prikamskii and Kaltasy formations, which, together with the overlying Nadezhdino Formation, are constituents of the Kyrpy Group corresponding either to the entire interval of the Lower Riphean, or to its greater part in the Volga–Urals region (Kozlov *et al.*, 1998; Maslov and Isherskaya, 1998; and references therein). Using the unified regional nomenclature, we can state that all identified microfossils characterize the middle, Kaltasy Formation of the Kyrpy Group. Within the formation, they occur in its basal Sauzovo Subformation of variegated dolomites and shales (2 samples; interval of 3253–3030 m) and in the Arlan Subformation of dark siltstones and shales conformably overlying basal rocks (24 samples; interval of 2884–2044 m). The Ashit Subformation of green dolomites crowning the Kaltasy Formation section is barren of microfossils.

Correlation of the Kyrpy and Burzyan groups between each other (see references in Kozlov *et al.*, 1998; Maslov and Isherskaya, 1998) is based on some structural features in common, geophysical data (seismic profiling), and oldest K–Ar dates ranging from 1520 to 1085 Ma and measured using sedimentary geochronometers of poorly known mineral composition from the Kyrpy Group (*Stratotip rifeya...*, 1983; and others). At the same time, other, mainly lithostratigraphic criteria stimulated some researchers to argue for similarity of the Kaltasy (and Kyrpy) deposits with the Karatavian (Katav–Min'yar), but not with Burzyanian succession (Aliev *et al.*, 1977). Scarce paleontological data available for the Kyrpy deposits are ambiguous. Judging from unpublished data of N.P. Panova and M.A. Semikhatov, single stromatolites known in the Kaltasy beds reveal similarity with transitional Lower Riphean forms. Likewise, rare microphytoliths from this formation can be attributed to either the Lower (Zabrodin, 1967), or Upper Riphean (Morozov and Revenko, 1969). As for previously published data on microfossils from the Kyrpy Group, their dimensions and peculiar morphologic features allowed Yankauskas (1982) and Kozlova (1990) to note and emphasize an undoubted affinity of distinguished morphotypes with those of the Karatavian biotas. As is shown below, new data are completely consistent with this conclusion.

MATERIALS AND METHODS

In total, 144 samples were examined and 47 of them (33%) yielded identifiable microfossils characterized by moderate and, sometimes (Nugush and Sal'nikovo microbiotas), by good preservation state. Microfossils of two indicated microbiotas have yellowish gray to orange coloration indicative of a low alteration of their organic substance, whereas gray and, sometimes, dark gray microfossils from other levels show that alteration was significantly more intense here.

The laboratory treatment of the material was performed using the complex method of extraction of microfossils (Veis and Vorob'eva, 1992, 1993). It included not only maceration of all samples in hydrofluoric acid, but also two subsequent interconnected procedures: (1) examination of the relatively large fraction (more than 50 μm) of insoluble residue under the binocular microscope to pick all large and/or complex morphotypes; and (2) centrifuging of residue after fractionation in the heavy liquid (specific weight of 2.1–2.2 g/cm^3). Combination of these two procedures provides best results and adequate information about both smallest (relatively simple) and largest (intricate) components of the examined biota. Most remarkable morphotypes from the examined samples are pictured in paleontological Plates I–III.

When analyzing the taxonomic diversity of microbiotas, we followed classification of Precambrian organic-walled forms accepted by Russian researchers

Plate I

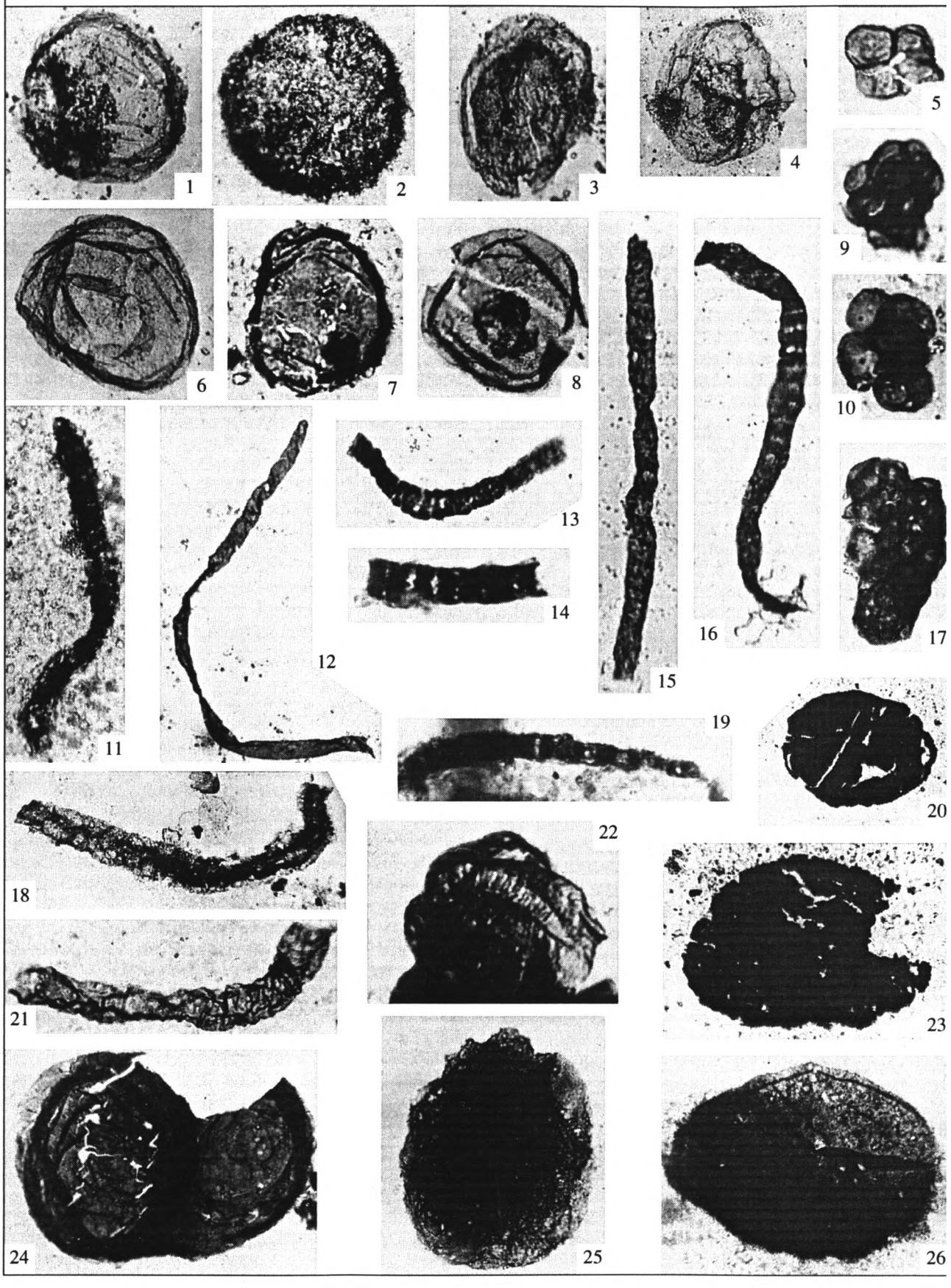


Plate I. Upper Precambrian microfossils from the southern Urals and adjacent region.

All specimens are stored at Geological Institute RAS, Moscow.

Geographic position of presented microfossils: (1, 2, 4, 6, 25) Kama–Belaya aulacogen; (3, 5, 7–24, 26) Bashkirian meganticlinorium; stratigraphic allocation: (1, 4) upper sublevel of the eighth level, Arlan Subformation, Kaltasy Formation, Kyrpy Group; Borehole Azino–Pal'niki-133, interval of 2068–2044 m; (2, 6, 25) seventh level, the same borehole, interval of 2357–2353 m; (3, 11, 26) third level, Nugush Subformation, Zil'merdak Formation, Karatau Group, 3 km west of the Inzer Settlement; (7, 8, 12, 17, 18, 21, 24) first level, the same location; (20, 23) Lemeza Subformation, Zil'merdak Formation, Karatau Group, 2 km east of the Inzer Settlement; (5, 9, 13–16, 19) Urtino Formation, Kuzha Group, the area of the abandoned Kuzha Settlement, Borehole 180, interval of 294–282 m; (10) Nizhnyaya Kuzha Formation, Kuzha Group, Borehole 150, interval of 153–140 m; (22) Urtino Formation, Borehole 158, interval of 130–120 m, the same locality. Scale bars corresponds to 225 μm in Fig. 1; 150 μm in Fig. 2, 26; 200 μm in Figs. 3, 15, 16; 270 μm in Figs. 4, 12; 50 μm in Figs. 5–7, 10, 22; 60 μm in Figs. 8, 13, 14, 16; 70 μm in Figs. 17, 23; 80 μm in Figs. 9, 11; 100 μm in Figs. 18–21, 24, 25.

(1, 4) *Leiosphaeridia incrassatula* Jank.; thin sphaeromorphic vesicles with dense callus-shaped thickening; (1) specimen 2054-565; (4) specimen 2056-585.

(2) *Spumosina rubiginosa* (Andr.), emend. Jank. et Medv., vesicles with spongy structure and probably lacking internal cavity, specimen 2355-1802.

(3) *Simia nerjenica* A. Weiss; fringed vesicles with distinct peripheral fold, specimen 9612-1552.

(5, 9, 10) *Myxococcoides inornata* Schopf, small structureless aggregates of coccoidal cells: (5) specimen 282-2913; (9) specimen 282-2920; (10) 153-1401.

(6, 24, 26) *Leosphaeridia crassa* (Naum.), emend. Jank.: (6) specimen 2355-575; (24) specimen 9612-503; (26) specimen 9612-822.

(7, 8) *Nucellosphaeridium minutum* Tim., sphaeromorphic vesicles with dark small inclusions (remnants of collapsed cytoplasm): (7) specimen 9612-570; (8) specimen 9612-413.

(11) *Polysphaeroides* sp., filamentous aggregate of small coccoidal cells forming transverse rows, specimen 9612-812.

(12) *Leiotrichoides typicus* Herm., emend. Herm., specimen 9612-512.

(13, 14, 16, 22) *Oscillatoriopsis* sp.: (13) specimen 282-2910; (14) specimen 282-2941; (16) specimen 282-2919; (22) unusual aggregate of glomerulate curved trichomes; specimen 158-134.

(15) *Leiotrichoides gracilis* Pjat., specimen 282-2949.

(17) botryose aggregate of coccoidal cells with the peculiar pleurocapsacean structure, specimen 9612-401.

(18, 21) thalluses of probable siphonocladacean algae ex gr. *Proterocladus*: (18) specimen 9612-4683; (21) specimen 9612-410.

(19) sheaths (presumable remains of cyanobacteria) composed of sections inserted into each other, close to *Circumvaginalis*, specimen 282-2845.

(20, 23) *Leiosphaeridia* sp., carbonified acritarchs of simple structure: (20) specimen 965-102; (23) specimen 965-103.

(25) *Pterospermopsimorpha* spp., highly corroded ellipsoidal envelope with thin filmy fringe, specimen 2355-573.

(as in Yankauskas *et al.*, 1989, with insignificant modifications). This classification includes, contrary to those used elsewhere, only the well-known taxons and is based on observable features of microfossils in order to minimize inferences from interpretation of their probable biological meaning (Knoll *et al.*, 1991; Butterfield *et al.*, 1994; Sergeev *et al.*, 1995). Let us consider now the taxonomic composition of examined microfossil assemblages starting with the Pal'niki microbiota from the Kyrpy Group of the Urals region.

COMPOSITION AND DISTRIBUTION OF EXAMINED MICROFOSSILS IN THE RIPHEAN OF THE SOUTHERN URALS AND VOLGA–URALS REGION

The Kama–Belaya aulacogen (Verkhnyaya Kama depression), the Kyrpy Group. In deposits of this group, organic-walled microfossils were first established by Yankauskas (1982). A very remarkable assemblage that was discovered from shales of the Arlan and Kaltasy formations (the Arlan Subformation of the Kaltasy Formation according to recent nomenclature) penetrated by boreholes Kaltasy-83 (interval of 3335–3295 m) and Arlan-7000 (interval of 2608–2255 m) included "...giant *Phycomycetes*, single trichomes of large oscillatoriacean algae, and filamentous algae *Eomycetopsis psilata* M. et S. visible to unaided eyes" (Yankauskas, 1982, p. 18). By morphology and preservation, these fossils were of a distinct Late Riphean appearance that was inconsistent, already at that time, with concepts suggesting the Early Riphean age of host deposits on the basis of general geological structure and isotopic dates obtained in the 1960s. However, a limited material that was at disposal of Yankauskas and opinion that the section recovered by both boreholes may be tectonically doubled were unfavorable at that time for the eventual conclusion on stratigraphic position of the discovered biota.

More representative data on the Kyrpy microfossils were later obtained by Kozlova (1990), who examined 93 samples from boreholes Menzelino–Aktanysh-203 (interval of 3409.0–2847.5 m) and Sula-20007 (interval of 3143.9–2250.4 m).[2] In deposits of the Prikamskii Formation (the Norkino and, partly Rotkovo subformations, according to her terminology) underlying the Kaltasy Formation, Kozlova discovered a diverse assemblage of acritarchs and filamentous forms, which included 13 genera and 10 species in total. In her opinion (Kozlova, 1990, p. 4), the abundant *Leiosphaeridia jacutica* (Tim.), *Vanavarataenia* sp., very wide fila-

[2] The location scheme of boreholes Kaltasy-83, Arlan-7000, Mezelino–Aktanysh-203, and Sula-20007 is published by Maslov and Isherskaya (1998, p. 4).

Plate II

Plate II. Upper Precambrian microfossils of the southern Urals and adjacent region.

All presented specimens are stored at Geological Institute RAS, Moscow.

Geographic position of pictured microfossils: (1–11, 13–15, 17, 19) Kama–Belaya aulacogen; (12, 16, 18, 20, 21) Bashkirian meganticlinorium. Stratigraphic allocation: (1–11, 13–15, 17, 19) upper sublevel of the eighth level, Arlan Subformation, Kaltasy Formation, Kyrpy Group, Borehole Azino–Pal'niki-133, interval of 2068–2044 m; (12, 20) first level, Nugush Subformation, Zil'merdak Formation, Karatau Group, 3 km west of the Inzer Settlement; (16, 18) third level, the same location; (21) third level, Tyul'men beds, the Ismakaevo Settlement, Borehole 26, interval 68–54 m. Scale bars correspond to 180 μm in Figs. 1, 6; 215 μm in Figs. 2, 4, 10; 120 μm in Figs. 3, 5, 9, 18, 19; 260 μm in Fig. 7; 160 μm in Figs. 8, 11–13; 200 μm in Fig. 14; 100 μm in Figs. 15, 17, 20, 21; 240 μm in Fig. 16.

(1–4, 6) *Palaeolyngbya sphaerocephala* Herm. et Pyl., wide thin filaments with the weak transverse structure of sheath and fragmentarily preserved trichomes: (1) specimen 2044-4603; (2) specimen 2052-5401; (3) specimen 2044-4604; (4) specimen 2046-4803; (6) specimen 2060-6202.

(5, 7, 17, 21) *Asperatofolium experatus* (Herm.), wide taeniate structures (sheaths): (5) specimen 2056-5811; (7) specimen 2056-5808; (17) specimen 2056-5802; (21) specimen 2688-684.

(8, 16) *Oscillatoriopsis* spp., large trichomes composed of short uniform cells: (8) specimen 2058-6003; (16) specimen 9612-810.

(9, 11, 13, 20) *Botuobia* spp., size-variable to giant trichome-like structures: (9) specimen 2064-6802; (11) specimen 2058-6002; (13) specimen 2056-5804; (20) 9612-414.

(10) *Plicatidium latum* Jank., wide tubular forms with thin transverse folds, specimen 2044-4618.

(12, 18) large tubular (?cuticular) structures with well-pronounced transverse ornamentation: (12) specimen 9612-402; (18) specimen 9612-811.

(14, 15) *Polytrichoides lineatus* Herm., emend. Herm.: (15) magnified fragment, specimen 2056-6002.

(19) Filamentous smooth-walled sheath enclosing elongated cells, specimen 2054-5608.

mentous vesicles and trichomes, and, in particular, large lophostriated *Valeria* vesicles present in the assemblage clearly indicates that "...the age of enclosing deposits cannot be older than the Late Riphean."

We subjected to the microphytological analysis 28 samples collected by Kozlov from the Sauzovo and Arlan subformations of the Kaltasy Formation of the Kyrpy Group penetrated in the depth interval of 3450.4–2044.0 m by Borehole Azino–Pal'niki-133 (Kozlov *et al.*, 1998). Microfossils of variable preservation degree are identifiable in 23 samples corresponding to eight conditionally defined microphytological levels: first (3253–3250 m; 1 sample), second (3040–3030 m; 1 sample), third (2884–2880 m; 1 sample), fourth (2822–2817 m; 1 sample), fifth (2765–2760 m; 1 sample), sixth (2572–2550 m; 4 samples), seventh (2357–2353 m; 2 samples), and eighth with two sublevels: lower (2076–2070 m; 3 samples) and upper one (2068–2044 m; 9 samples). The first and second levels are inside the Sauzovo Subformation, whereas six others characterize the Arlan Subformation of the Kaltasy Formation. Five samples from depth levels of 3450, 2081, 2076, 2077, and 2070–2069 m were barren of microfossils and some of them, of dispersed organic matter as well. The latter is persistently present as an accessory or significant admixture in all samples that yielded microfossils. Position of examined samples in the section, main characteristic morphotypes, and two parameters of their abundance rate are shown in Fig. 2.

The Sauzovo Subformation of the Kaltasy Formation. The first level (3253–3250 m) is characterized by presence of rare dark-colored acritarchs *Leiosphaeridia*[3] (up to 100 μm) and more abundant filamentous sheaths of *Eomycetopsis* (3–4 μm), both occurring as single specimens and forming dense mate-shaped accumulations. *The second level* (3040–3030 m) yields only single, highly decomposed acritarchs *Leiosphaeridia* (to 120 μm).

The Arlan Subformation of the Kaltasy Formation. Predominant at *the third level* (2884–2880 m) are acritarchs *Leiosphaeridia* of two size generations (120–160 and 200 μm), sheaths of *Leiotrichoides* (10–12 μm), and elongated structureless filaments (thalluses are 20–40 μm wide). Less common are small *Leiosphaeridia* (up to 70 μm), thalluses narrowest of all recorded in the examined selection (10–20 μm), as well as their wider branching representatives (up to 60 μm) and *Caudosphaera* vesicles with a long protrusion (to 150 μm).

The fourth level (2822–2817 m) is marked by abundance of medium-sized thalluses ex. gr. *Pseudodendron* with longitudinal ornamentation (40–60 μm). These associate with narrower varieties of similar structure (20 μm), large *Archaeoclada* thalluses with well-developed lateral branching (fragment size amounts to hundreds of micrometers), and filamentous sheaths of *Leiotrichoides* (10–12 μm).

The fifth level (2765–2760 m) is dominated by structureless taeniate thalluses (16–18 and 20–30 μm). Less common components are represented by acritarchs *Leiosphaeridia* (90–100 and 190 μm), *Chuaria* (to 600 μm), sheaths of *Leiotrichoides* (10–12 μm), *Caudosphaera* vesicles (40–50 μm) with very long protrusion, and large branching thalluses of *Archaeoclada* (fragments up to 300 μm in size and greater).

The sixth level (2572–2550 m) is characterized by relatively abundant thick-walled acritarchs *Leiosphaeridia* (180–200 μm) associated with rare and large *Chuaria* (up to 430 μm), spongy *Spumosina* vesicles (300 μm), and small *Nucellosphaeridium* (40–50 μm). Other morphotypes are represented by multiserial sheaths of *Polytrichoides* (up to 20 μm) and *Eomicrocoleus* (up to 30 μm and more), by transversely orna-

[3] The species composition of all microfossils from the southern Urals and adjacent region is cited in explanations to Figures 2 and 3, and also in paleontological Plates I–III.

Plate III

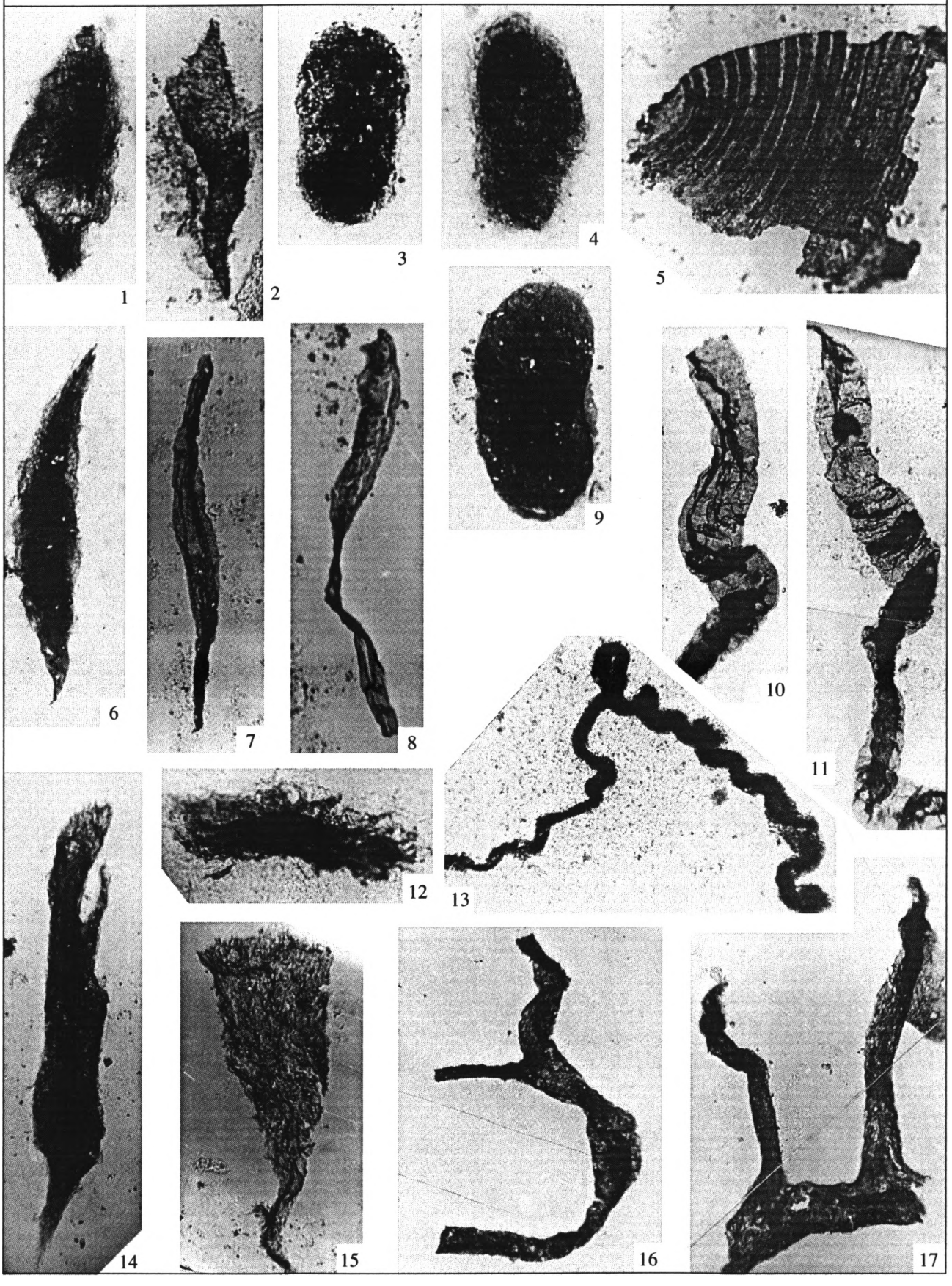


Plate III. Upper Precambrian microfossils of the southern Urals and adjacent region.

All presented specimens are stored at Geological Institute RAS, Moscow.

Geographic position of pictured microfossils: (1–8, 12, 13, 15–17) Kama–Belaya aulacogen; (9–11, 14) Bashkirian meganticlinorium. Stratigraphic allocation: (8, 17) fourth level, Arlan Subformation, Kaltasy Formation, Kyrpy Group; Borehole Azino–Pal'niki-133, interval of 2822–2817 m; (16) fifth level, interval of 2765–2760 m, the same location; (13) sixth level, interval of 2572–2550 m, the same location; (1, 6) seventh level, interval of 2357-2353 m, the same location; (1–5, 7, 12, 15) upper sublevel of the eighth level, interval of 2068–2044 m, the same location; (9–11, 14) first level, Nugush Subformation, Zil'merdak Formation, Karatau Group, 3 km west of the Inzer Settlement. Scale bars correspond to 200 μm in Figs. 1, 2, 6–8, 16; 180 μm in Figs. 3, 4, 9; 100 μm in Figs. 5, 10, 11; 400 μm in Fig. 13; 250 μm in Fig. 14; 85 μm in Fig. 15.

(1, 3, 4, 9) Fusiform and ellipsoidal spongy microfossils of the unclear biological nature close to *Fabiformis*: (1) specimen 2355-551; (3) 2046-4813; (4) 2046-4806; (9) specimen 9612-504.

(2, 15) Thin-walled conical microfossils resembling Lower Paleozoic *Ceraphyton*: (2) specimens 2060-6407; (15) specimen 2056-587.

(5) Fragment (terminal part) of the giant trichome-like structure ex gr. *Botuobia*, specimen 2052-5408.

(6) *Pellicularia tenera* Jank., specimen 2353-551.

(7, 8, 10, 11, 13) Taeniate thalluses with the different structure and, probably, belonging to different taxons: (7) specimen 2046-4815; (8) Thallus with the longitudinal fissure, specimen 2817-2810; (10, 11) thalluses ex gr. *Proterocladus* (probable remnants of ancient siphonocladacean algae): (10) specimen 9612-411, Specimen 9612-416; (13) fragment of the thallus coiled into the flat spire, specimen 2556-604.

(14) *Majaphyton antiquam* Tim. et Herm., trilobate thallus (every lobe is characterized by the different structure), specimen 9612-6401.

(16, 17) *Archaeoclada* sp., large branching thalluses of presumably ancient green algae: specimen 2760-2764; specimen 2817-2801.

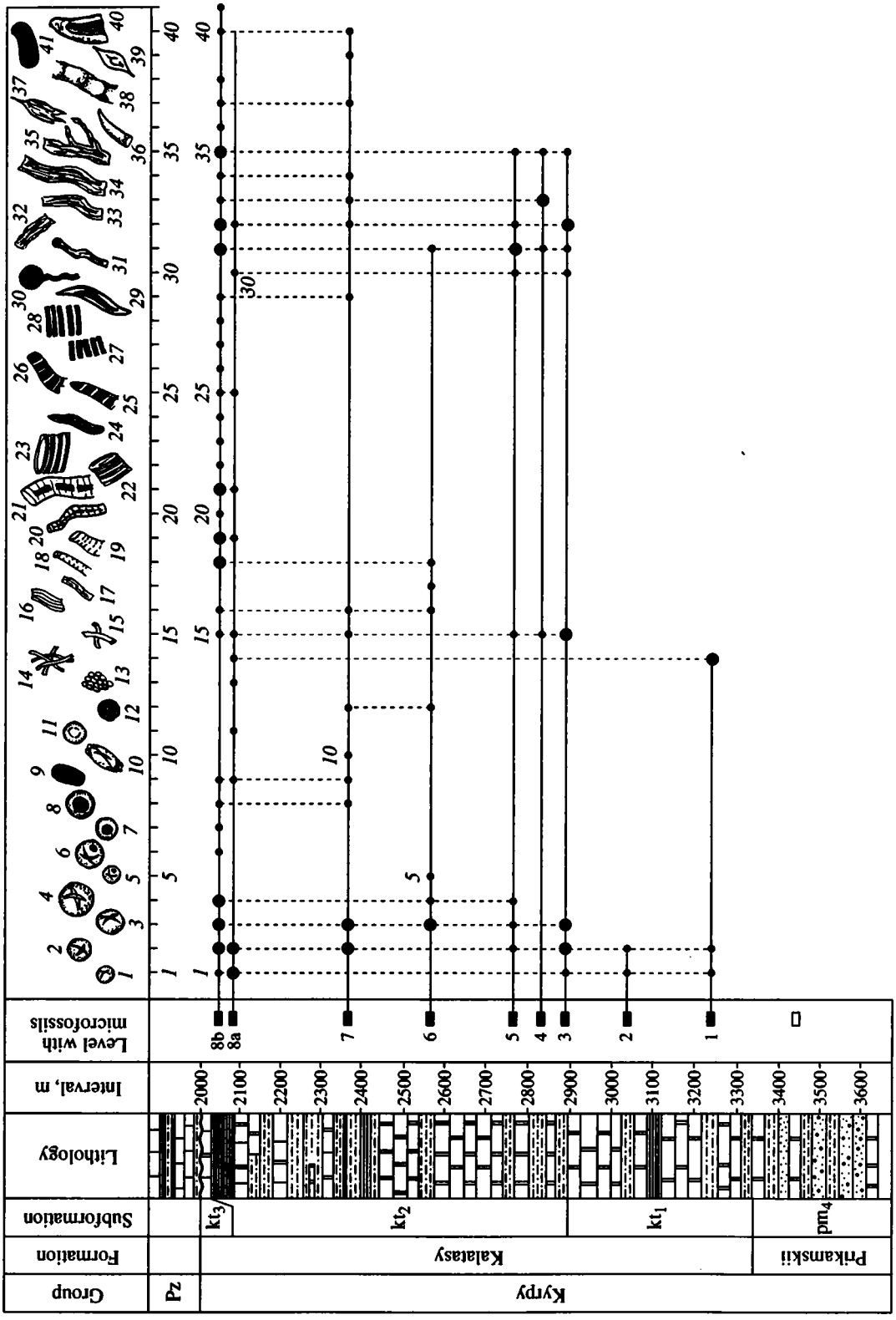
mented *Siphonophycus* (22–30 μm), and by single thalluses ex. gr. *Pseudodendron* with weak longitudinal ornamentation (20 μm) sometimes forming a flat spire.

The seventh level (2357–2353 m) is marked by abundance of medium-sized *Leiosphaeridia* (100–120 and 150–200 μm). The acritarch assemblage also includes *Spumosina* (110 μm), oval *Navifusa* (230–260 × 110–120 μm), *Pterospermopsimorpha* (159 μm) enclosing a large body, and a single specimen of acanthomorphic *?Prolataforma* (450 μm) that was destroyed during maceration. Other taxons of this level are represented by *Leiotrichoides* (10–12 μm), *Polytrichoides* (up to 20 μm), and sufficiently abundant intricate morphotypes. The latter include wide non-branching structureless thalluses (64–68 μm), their narrower varieties ex gr. *Pseudodendron* with longitudinal ornamentation (20 and 38–40 μm), large fusiform *Pellicularia* (300 × 60 μm), and several new taxons (most characteristic amid them are subtriangular capsules with a dark internal filling).

The eight level. Dominant components of its *lower sublevel* (2076–2070 m) are small acritarchs *Leiosphaeridia* (50–60 and 80–140 μm), less common *Navifusa* (250 × 100 μm), and *Simia* (90 μm). Colonial coccoidal *Ostiana* rare in the Kyrpy assemblages occur here in a form of small structureless thalluses (diameter of cells 20 μm, thallus size 150–200 μm). In addition, the sublevel is marked by presence of *Eomycetopsis* (3–4 μm), *Leiotrichoides* (10–12 μm), transversely ornamented *Syphophycus* (32–44 μm), wide oscillatorian trichomes (34 μm), and filaments of *Palaeolyngbya sphaerocephala* Herm. et Pyl. (up to 50 μm). Forms with the intricate structure are *Caudosphaera* (to 200 μm) and thalluses ex gr. *Pseudodendron* with longitudinal ornamentation (30 μm).

The second sublevel (2068–2049 m) shows the peak abundance of organic-walled forms present in the Pal'niki microbiota. Dominant here are acritarchs *Leiosphaeridia* (80–140 and 170–220 μm) and *Chuaria* (400–450 μm), transversely ornamented *Siphonophycus* sheaths (22–34 and 50–60 μm), filaments of *Palaeolyngbya sphaerocephala* Herm. et Pyl. (to 70 μm), thalluses ex gr. *Pseudodendron* with longitudinal ornamentation (10–12 and 24–26 μm), and larger branching thalluses of *Archaeoclada* with swellings at the end of branches (to 80 μm). This group of abundant taxons is less diverse than small acritarchs *Leiosphaeridia* (up to 60 μm), *Nucellosphaeridium* (130 μm), *Pterospermopsimorpha* (70–90 and 120–160 μm), *Navifusa* (160 × 90 μm), size-variable rugose–costate tubular *Rectia* and *Plicatidium* (? cuticular covers; 100–140 and 200–210 μm, respectively), and *Botuobia*-like trichomes (40–50 and 100 μm), their giant varieties (up to 140–160 μm) included. List of other morphotypes characterizing the sublevel is as follows: relatively simple *Leiotrichoides* vesicles (10–12 μm), multiserial *Polytrichoides* (24–26 μm), corroded filaments of *Asperatofilum* (40–50 μm), elongated–ellipsoidal *Brevitrichoides* (110 × 12 μm), oscillatorian trichomes of variable structures (including unusually large *Oscillatoriopsis*, up to 70 μm in size), oval *Fabiformis*-like spongy structures (180 × 90 μm), fusiform *Pellicularia* (200 × 40 μm), and structureless elongated thalluses (42–48 and 60–90 μm). New morphotypes of the sublevel are remarkably large and thin subtriangular forms (up to 300 μm) and thalluses having the well-expressed acute (?basal) protrusion and several lobes (more than 500 μm).

In general, the organic-walled Pal'niki microbiota from studied deposits is sufficiently representative and includes 25 genera and 23 species of known microfossils, and several new taxons. Morphotypes most abundant of this microbiota are filamentous acritarchs (mainly their medium-sized varieties, the ornamented


Group
Formation
Subformation
Lithology
Interval, m
Level with microfossils
Pz
Kyrpy
Kalatasy
Prikamskii
kt3
kt2
kt1
pm4
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
8b
8a
7
6
5
4
3
2
1

vesicles and/or cuticles included) and taeniate thalluses, some of which demonstrate a clear branching. These morphotypes are slightly more abundant than trichomes, trichome-like structures, and representatives of new taxons. The least abundant in microbiota are colonial coccoidal forms represented by few specimens. By abundance and diversity (and, partly, by dimensions and structure complexity), the distinguished microfossils can be subdivided into three assemblages: most impoverished (first and second levels of the Sauzovo Subformation), most representative (upper sublevel of the eighth level in the Arlan Subformation), and transitional (third level–lower sublevel of the eighth level in the same subformation). Without more detailed microphytological data, additional sedimentological study and relevant paleoecological reconstructions, we do not consider difference between assemblages as having a significant stratigraphic potential and discuss them further as representing single microbiota.

However, three distinct groupings of microfossils can be distinguished on the basis of their geographic and stratigraphic distribution. The first of them includes only simple acritarchs *Leiosphaeridia, Nucellosphaeridium, Pterospermopsimorpha*, filamentous *Eomycetopsis* and *Leiotrichoides*, as well as narrow non-branching thalluses. These forms are known as components of the Riphean and many pre-Riphean and Vendian microbiotas from northern Eurasia and other regions and are of a low potential for dating the Kyrpy Group.

The second grouping is represented by new forms, which include at least five complex morphotypes, whose significance is unknown. The third grouping of microfossils is, in our opinion, of a high stratigraphic potential. It includes (disregarding new forms) more than a half of taxons distinguished in the Pal'niki microbiota. As is shown in subsequent taxonomic analysis of this grouping, its potential cannot be considered as indisputable, because microbiotas of similar composition are registered in deposits of some regions, the very wide stratigraphic interval of which is assumed on the basis of isotopic–geochronological and, partly, chemostratigraphic data. This ambiguity steaming from two different (biostratigraphic and geochronological) approaches to interpretation of Precambrian microfossils was discussed previously (Veis, 1995). The presumable stratigraphic position of the Pal'niki microbiota amid other microfossils from the Riphean stratotype will be discussed after the analysis of taxonomic composition of new microbiotas discovered in the Yurmatinian–Karatavian boundary sequences of the Bashkirian meganticlinorium.

The Bashkirian meganticlinorium, the Kuzha Group. Microfossils from deposits of this group have never been studied. In the adjacent platform areas of Bashkortostan (southwest of Ufa), two peculiar microbiotas were discovered however by Yankauskas (1982) in the Tukaevo and Akberdino formations (lower part of the Ol'khovka Formation, according to recent nomenclature) penetrated by Borehole Kabakovo-62 in the intervals of 5100–5099 and 4762–4745 m, respectively. As noted above, Filippov (1997) refers analogues of precisely these deposits to the Kuzha Group. Actually, both mentioned intervals in Borehole Kabakovo-62 yield identical microfossil assemblages of simple filamentous vesicles, large acritarchs *Leiosphaeridia* (more than 200 μm across), tabular *Satka* (from 50 to 100 μm and more across), very peculiar lophostriated *Valeria* vesicles (to 450 μm) reaching dimensions of *Chuaria* and first discovered at this locality, and also some other less important and fragmentary microfossils.

Yankauskas (1982) considered these microfossils and, correspondingly, the enclosing Tukaevo–Akberdino (Ol'khovka) succession as undoubtedly corresponding in age to the Late Riphean. He correlated them with the lowermost Karatavian microphytological

Fig. 2. Stratigraphic distribution of organic-walled microfossils in the Upper Precambrian Kyrpy Group (Borehole Azin–Pal'nikivskaya-133).

Pictured morphotypes: (*1*) *Leiosphaeridia crassa* (Naum.), emend. Jank., vesicles < 70 μm; (*2*) *L. exculpta* (Tim.), emend. Mikh., vesicles 70–150 μm; (*3*) *L. jacutica* (Tim.), emend. Mikh. et Jank. and/or *L. incrassatula* Jank., vesicles 150–300 μm; (*4*) *Chuaria circularis* Walk., emend. Vidal et Ford, vesicles > 300 μm; (*5*) *Nucellosphaeridium minutum* Tim., external envelope <100 μm; (*6*) *N. nordium* (Tim.), external envelope >100 μm; (*7*) *Pterospermopsimorpha capsulata* Jank., external envelope <90 μm; (*8*) *N. piletiformis* Tim., emend. Mikh., external envelope >90 μm; (*9*) *Navifusa majensis* Pjat.; (*10*) *?Prolatoforma* sp.; (*11*) *Simia* sp.; (*12*) *Spumosina rubiginosa* (Andr.), emend. Jank. er Medv.; (*13*) *Ostiana microcystis* Herm.; (*14*) *Eomycetopsis robusta* Schopf, emend. Knoll et Golubic; (*15*) *Leiotrichoides typicus* Herm., emend. Herm.; (*16*) *Polytrichoides lineatus* Herm., emend. Herm.; (*17*) *Eomicrocoleus crassus* Horod. et Donald.; (*18*) *Siphonophycus* sp. I, shaths 20–40 μm wide, having transverse ornamentation; (*19*) *S.* sp. II, transversely ornamented shaths 40–60 μm wide; (*20*) *Asperatofilum experatus* (Herm.); (*21*) *Palaeolyngbya sphaerocephala* Herm. et Pyl.; (*22*) *Rectia costata* (Jank.), ornamented tubular structures or cuticles 50–100 μm wide; (*23*) *Plicatidium latum* Jank., morphotypes close to the previous ones but wider (to 200–210 μm); (*24*) *Brevitrichoides bashkiricus* Jank.; (*25*) *Oscillatoriopsis* spp., large trichomes (30–40 μm wide); (*26*) *Oscillatoriopsis* spp., very large trichomes (40–70 μm wide); (*27*) *Botuobia* spp., large trichome-like structures (40–100 μm wide); (*28*) *Botuobia* spp., very large trichome-like structures (to 140–160 μm wide); (*29*) *Pellicularia tenera* Jank.; (*30*) *Caudosphaera expansa* Herm. et Tim.; (*31–34*) taeniate thalluses of different width (10–20, 20–40, 40–60, and 60–90 μm, respectively), those ex gr. *Pseudodendron* included; (*35*) branching thalluses *Archaeoclada* sp.; (*36–40*) new morphotypes of variable intricate structure; (*41*) *Fabiformis*-like specimens.

Numbers and letters near solid rectangles designate microphytological levels and sublevels; open rectangles correspond to samples barren of microfossils; solid circles indicate occurrence level and relative abundance of single or rare (small circles) and numerous (large circles) specimens (other symbols as in Fig. 3).

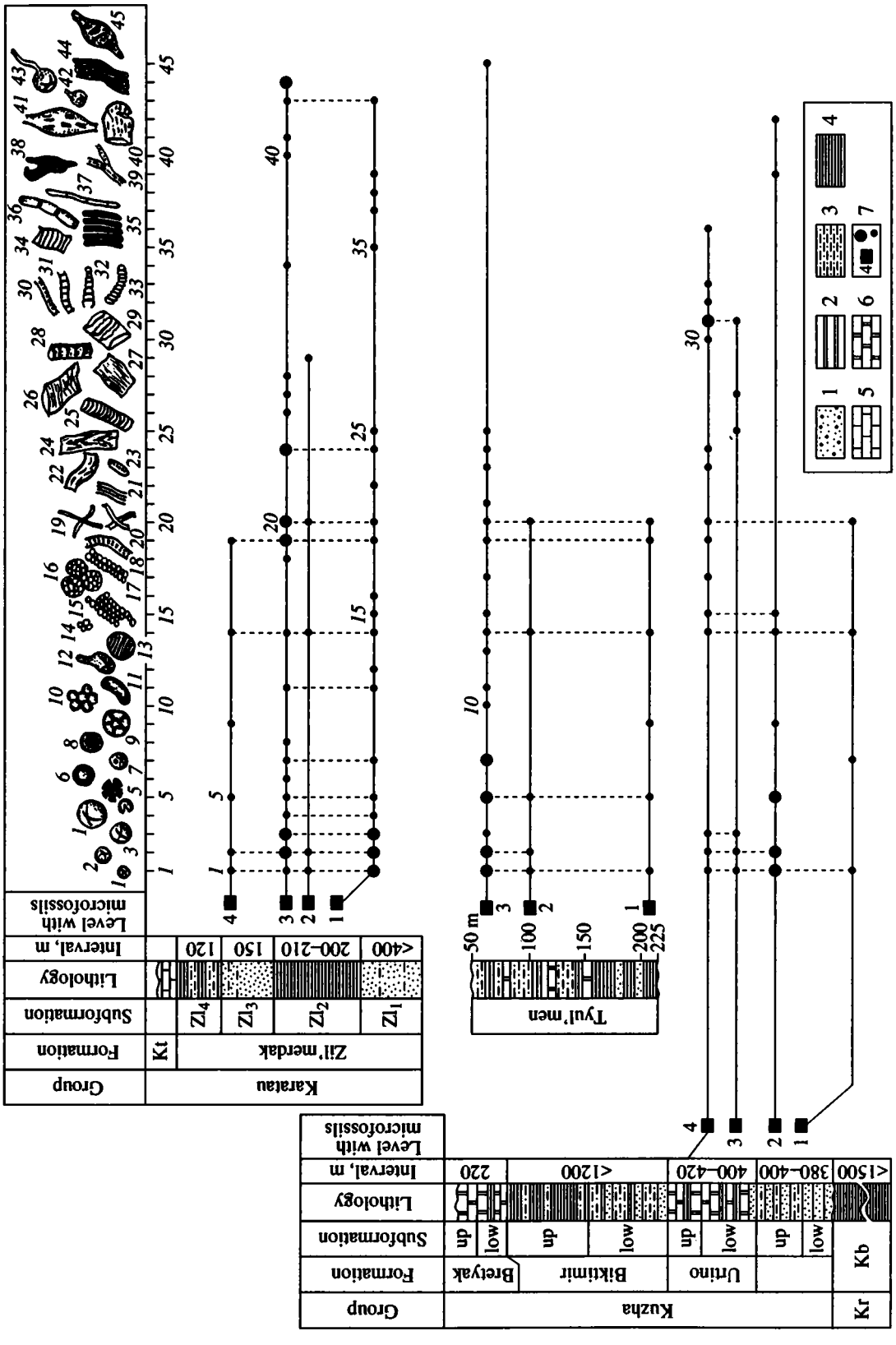

Group
Formation
Subformation
Lithology
Interval, m
Level with microfossils
Karatau
Kt
Zil'merdak
Zl1Z
Zl2Z
Zl3Z
Zl4Z
<400
200–210
150
120
Tyul'men
50 m
100
150
200
225
Kuzha
Betyak
Biktimir
Urino
Kb
Kr
220
<1200
400–420
380–400
<1500
up
low
dn
1
2
3
4
5
6
7

Fig. 3. Stratigraphic distribution of organic-walled microfossils in the examined Riphean deposits of the southern Urals.

Lithology: (1) sandstone and/or conglomerates, (2) low-carbonaceous argillite, (3) siltstone, (4) argillite; (5) limestone, (6) dolomite; (7) microphytological levels (solid rectangles) and occurrence levels of abundant (large circles) and single or rare microfossils (small circles).

Pictured morphotypes: (*1*) *Leiosphaeridia crassa* (Naum.), emend. Jank., vesicles < 70 μm; (*2*) *L. exsculpta* (Tim.), emend. Mikh., vesicles 70–150 μm; (*3*) *L. jacutica* (Tim.), emend. Mikh. et Jank., vesicles 150–300 μm; (*4*) *Chuaria circularis* Walk., emend. Vidal et Ford, vesicles >300 μm; (*5*) small vesicles with median (*L. bicrura* Jank.) and peripheral (*L. ternata* (Tim.) emend. Mikh. et Jank.) gaps; (*6*) *Simia nerjenica* A. Weiss; (*7*) *Nucellosphaeridium minutum* Tim., external envelope <100 μm; (*8*) *Pterospermopsimorpha pileiformis* Tim., emend. Mikh., external envelope >100 μm; (*9*) *Satka colonialica* Jank.; (*10*) cenobial aggregates of small vesicles *Leiosphaeridia* sp.; (*11*) *Navifusa majensis* Pjat.; (*12*) large acritarchs of the irregular shape (monstrous vesicles); (*13*) *Valeria lophostriata* Jank.; (*14*) *Myxococcoides* spp.; (*15*) *Ostiana microcystis* Herm.; (*16*) *Coniunctiophycus totticus* A. Weiss; (*17*) *Sphaerocongregus variabilis* Moor.; (*18*) *Polysphaeroides* sp.; (*19*) Eomycetopsis robusta Schopf, emend. Knoll et Golubic; (*20*) *Leiotrichoides typicus* Herm., emend. Herm. and/or *L. gracillis* Pjat.; (*21*) *Polytrichoides lineatus* Herm., emend. Herm.; (*22*) *Eomicrocoleus crassus* Horod. et Donald.; (*23*) *Archaeoellipsoides* spp.; (*24*) *Asperatofilum experatus* (Herm.); (*25*) *Siphonophycus* spp.; (*26*) *Plicatidium latum* Jank.; (*27*) *Taenitrichoides jaryschevicus* Asseeva; (*28*) *Rectia costata* (Jank.); (*29*) wide (>90 μm) thin-walled tubular structures (?sheaths); (*30*) *Palaeolyngbya* sp.; (*31*) *Oscillatoriopsis* spp.; (*32*) *Cephalophytarion* sp.; (*33*) *Filiconstrictosus* sp.; (*34*) *Botuobia magna* (Tynni et Donner); (*35*) giant (>100 μm) trichome-like structures; (*36*) *Trachytrichoides ovalis* Herm.; (*37*) thalluses ex gr. *Proterocladus* composed of elongated cells; (*38*) *Majaphyton antiquam* Tim. et. Herm.; (*39*) branching thalluses ex gr. *Pseudodendron* with weak longitudinal ornamentation; (*40*) *Lakhandinia* sp.; (*41*) fusiform structures with thin internal filaments (*?Eomicrocoleus*); (*42*) *Germinosphaera unispinosa* Mikh.; (*43*) *Caudosphaera expansa* Tim. et Herm.; (*44*) wide dense filaments (thalluses); (*45*) *Brevitrichoides tiulmenicus* Jank. et Kozl.

Other symbols: (Kr) presumably Kyrpin Group; (Kb) presumably Kabakovo Formation (Kurgas Complex of black shales); (Kt) Katav Formation.

level that was unfortunately termed as the Kabakovo level.[4] Eponym of the level is Borehole Kabakovo-62, but not the lithostratigraphic unit, and the name is confusing indeed. Correlating the level in question with the Bir'yan Subformation of the Karatavian Zil'merdak Formation, Yankauskas placed it at the base of the Upper Riphean, below the next Muldakaevo (Bederysh) level of the same formation integrated in the general succession of Uralian microbiotas. Transition between these two levels was considered as representing the most distinct biostratigraphic boundary in the entire succession of Riphean microfossils in the southern Urals (Keller and Yankauskas, 1980; Yankauskas, 1982; and others).

As mentioned above, 68 samples from the Kuzha Group were subjected to the microphytological analysis. Samples were collected from outcrops in the Kuzha River valley and from cores of more than 20 boreholes drilled in the adjacent areas (the area of the abandoned Kuzha Settlement). Microfossils were discovered in 13 samples at four microphytological levels within the Nizhnyaya Kuzha Formation (first and second levels; 3 and 4 samples, correspondingly) and Urtino Formation (third and fourth levels; 4 and 2 samples, respectively). The established microbiotas are characterized by the following taxonomic composition.

The Nizhnyaya Kuzha Formation. The first level (Borehole 150; interval of 190–177 m) is marked by abundance of small acritarchs *Leiosphaeridia* (30–50 μm) and *Nucellosphaeridium* (30 μm). They are accompanied by less abundant colonial coccoidal *Myxococcoides* with two cell generations (14–16 and 18–20 μm) and by single *Leiotrichoides* vesicles 6–8 μm wide (Fig. 3).

The second level (Borehole 150; interval of 153–140 m) is characterized by more diverse assemblage of organic-walled microfossils. Its peculiar forms are small and medium-sized acritarchs *Leiosphaeridia* (20–30 μm, less commonly, up to 50 μm) occurring everywhere and representing background forms. *Leiosphaeridia* varieties smaller in size are represented by many hundreds of specimens; most of them have a peculiar median or peripheral gaps and are identified as *L. bicrura* Jank. and *L. ternata* (Tim.). Other acritarchs have an envelope of the tabular (herkomorphic) structure and are referred to the *Satka* genus (30–40 μm). Colonial coccoidal microfossils are substantially less abundant than acritarchs. They include *Myxococcoides* (cell diameter of 16 and 20 μm) and fragmented *Ostiana* thalluses (cell diameter of 10–14 μm; fragments up to 100 μm in size). The assemblage of the second level also includes small *Germinosphaera* vesicles with single protrusions, which probably represent intergrowth structures of algae and/or fungi (20–30 μm), and single branching? thalluses ex gr. *Pseudodendron* with weak longitudinal ornamentation (branch width ranges from 10 to 40 μm).

The Urtino Formation. The third level (Borehole 158; interval of 130–120 m) is again rich in acritarchs *Leiosphaeridia*, some varieties of which are larger than those characterizing two previous levels (120–160 μm). They are accompanied by filamentous tubular structures of two types: relatively narrow *Siphonophycus* (40 μm wide) with a distinct transverse structure and very wide *Taenitrichoides* (90 μm), which are either smooth-walled or having a weak transverse ornamentation. In addition, filamentous forms are also represented by fragmentary trichomes *Oscillatoriopsis* (10 μm wide) sometimes forming peculiar glomerulate interweaving (Plate I, Fig. 22).

The fourth level. (Borehole 180; interval of 294–282 m) is characterized by the most diverse and abun-

[4] Based on geophysical and some isotopic–geochronological data, other researchers refer the Tukaevo and Ol'khovka sequences to the Middle Riphean (for references see Maslov and Isherskaya, 1998).

dant assemblage of Kuzha microfossils. The assemblage contains abundant acritarchs *Leiosphaeridia* (60–150 μm), separate vesicles up to 200 μm in diameter included. Colonial coccoidal microfossils are represented here by three morphotypes: small structureless *Myxococcoides* (cell diameter from 10–12 to 14–16 μm), *Ostiana* thalluses (cell diameter 18 μm), and chain fragments of large biserial *Sphaerocongregus* (cell diameter 30 μm). Other taxons of the assemblage are filamentous *Eomycetopsis* (4 μm) and *Leiotrichoides* (up to 20 μm), akinete-like *Archaeoellipsoides* (10–12 × 30 μm), abundant trichomes *Oscillatoriopsis* (8–14 μm), *Cephalophytarion* (6 μm), *Filiconstrictosus* (9 μm), *Palaeolyngbya* (8–10 μm), and single trichome-like *Trachytrichoides* consisting of elongated dolioform cells joined into filaments (cell dimensions are 40 × 50 μm).

Thus, the Kuzha microfossils belong to 18 genera and 17 species (Fig. 3). Similarly to constituents of the Pal'niki microbiota, they are represented by taxons differing in their stratigraphic potential. With regard to abundance, sharply preponderant amid Kuzha morphotypes are transitional forms of the very simple structure (*Leiosphaeridia, Myxococcoides, Leiotrichoides*, and others). Other, subordinate morphotypes (*Ostiana, Taenitrichoides, Sphaerocongregus*, and others) are of a narrower stratigraphic range. In all representative Riphean sections they occur only in the upper, Karatavian part, although based on isotopic–geochronological data, some authors express a different standpoint (see below).

The Tyul'men Beds (Borehole 28; interval of 225–54 m) contain microbiota, which was discovered by Kozlova (1987), who repeatedly revised it together with Yankauskas and Veis (Yankauskas *et al.*, 1989; Veis *et al.*, 1990; Kozlova, 1993; and others).[5] As a result, the adequate though irregular characteristics of microfossils from these deposits could be refined to a minor extent on the basis of new materials. The data obtained indicate that most of the Tyul'men microfossils correspond to three microphytological levels, where assemblages are different in composition, abundance, and preservation state (Fig. 3). Only single simple microfossils of poor preservation occur outside these levels.

The first level (interval of 223–207 m) is characterized by a very impoverished assemblage of rare small acritarchs *Leiosphaeridia* (16–30 μm in diameter) including *L. bicrura* Jank. and *L. ternata* (Tim.), which associate with fragmented *Satka* vesicles (32–36 μm), several specimens of colonial coccoidal *Myxococcoides* (10–12 μm), and with single filamentous *Eomycetopsis* (3–4 μm) and *Leiotrichoides* (8–10 μm).

The second level (interval of 117–88 m) yielded microfossils slightly more abundant but taxonomically similar to forms of previous assemblage. Quantitative proportions and dimensions of some morphotypes are also different here. For instance, *Leiosphaeridia* forms widespread at this level are frequently represented by closed vesicles (up to 70 μm), but species with peripheral (*L. ternata*) and median (*L. bicrura*) breaks occur as single specimens (16–20 μm). An insignificant increase in cell dimensions is characteristic of rare *Myxococcoides* colonies (up to 18 μm), and width of *Leiotrichoides* vesicles comparable in abundance become larger (up to 16 μm).

The third level (interval of 68–54 m) yielded an assemblage sharply differing in main parameters from two previous microbiotas. The assemblage includes abundant small *Leiosphaeridia* (including *L. bicrura* and *L. ternata*) and *Nucellosphaeridium* forms (dimensions of both morphotypes range from 10–12 to 30 μm). We counted thousands of their specimens sharply prevailing in examined samples (like at the second Nizhnyaya Kuzha level in the Kuzha Formation). In addition to these forms, the assemblage also includes abundant larger *Leiosphaeridia* (up to 150 and, sometimes, to 270 μm), cyanobacterial aggregates of vesicles belonging to the same genus (diameter of envelopes up to 30 μm and that of aggregates, up to 180 μm), oval *Navifusa* (200 × 240 μm), and very peculiar lophostriated *Valeria* (up to 300 μm and more). Colonial coccoidal forms are represented at this level by *Myxococcoides* of two size generations (8–10 and 20 μm), by elongated fragments of *Ostiana* thalluses (cell size is 20–22 μm), and by chain aggregates of *Sphaerocongregus* (cell diameter amounts to 18–20 μm). In addition to *Eomycetopsis* and *Leiotrichoides* inherited from underlying deposits, filamentous sheaths are represented by a group of taxons that consists of multiserial *Polytrichoides* (the width of separate filaments is up to 4 μm and that of aggregates, up to 30 μm), wide structureless *Asperatofilum* (up to 60 μm), fragmented *Siphophycus* sheaths with a distinct transverse structure (up to 40 μm), ellipsoidal *Archaeoellipsoides* (10–30 × 30–110 μm), and larger fusiform *Brevitrichoides tiulmenicus* Jank. et Kozl. (100–110 × 220–240 μm), which probably have the multicellular structure.

Thus, the Tyul'men microbiota includes at least 15 genera and 19 species differing in the structure and/or dimensions. The results obtained substantially change its previous taxonomic characteristics, because only 11 genera and 13 species were known earlier (Kozlova, 1987, 1993; Yankauskas *et al.*, 1989; Veis *et al.*, 1990). It is noteworthy that newly recognized forms belong to *Navifusa, Ostiana, Sphaerocongregus, Polytrichoides, Asperatofilum*, and other genera widespread in the Karatavian sequences, whereas composition of transient morphotypes such as *Myxococcoides, Eomycetopsis*, and some acritarchs is insignificantly changed.

The Karatau Group. Rocks of this group were studied and sampled in different sections of the Bashkirian meganticlinorium, but new important data were

[5] Taking into consideration the debatable status of Tyul'men beds, we consider them as representing a regional unit of an open nomenclature.

obtained only for the middle part of the Zil'merdak Formation in two localities near the Inzer Settlement. In the first locality, an almost continuous succession thoroughly studied includes all four subformations of the unit (from the Bir'yan Subformation to the Bederysh Subformation). The rocks under consideration are exposed in fresh road excavations along the Ufa–Beloretsk road, in the area stretching from the peculiar loop-shaped bend (the so-called mother-in-law tongue) to the western margin of the Inzer Settlement, whereas the section in the second locality includes only upper Lemeza and Bederysh subformations, whose beds are exposed near the bridge across the Malyi Inzer River and in the valley of the latter, 2 km east of the settlement. The eastern exposure yielded an impoverished assemblage of Lemeza microfossils and the western one, a very representative Nugush microbiota.

The Nugush Subformation. Microfossils characterize the 50-m-thick interval of the subformation section 130–180 m above its base, where deposits are represented by greenish gray thin- and obscurely bedded shales and siltstones. Microfossils are buried here at three microphytological levels (Fig. 3), which show substantially different diversity and abundance of taxons.

The first level (interval from 130–134 to 140–145 m above the base of subformation) is characterized by abundant acritarchs *Leiosphaeridia* (from 30–50 to 180–200 μm) including *L. bicrura* and *L. ternata* (both are 20–30 μm in diameter), rare fragments of dark *Chuaria* (up to 320–330 μm in diameter), *Nucellosphaeridium* having internal inclusions (50–60 μm), oval *Navifusa* (90 × 180 μm), and single vesicles of irregular shape (monstrous forms). They are accompanied by colonial coccoidal *Myxococcoides* (cell diameter is 10–14 μm), *Ostiana* thalluses (cell diameter amounts to 20 μm), and by aggregates composed of several subspherical colonies of *Coniunctiophycus* (diameter of cells is 18–20 μm, of colonies to 70 μm, and that of aggregates, up to 200 μm and more). Filamentous morphotypes include *Eomycetopsis* (3–4 μm) and *Leiotrichoides* (6–7 μm) sheaths occurring as isolated specimens or forming small mats, larger *L. gracilis* Pjat. (up to 26–30 μm), wide non-septate smooth-walled *Asperatofilum* (from 30 to 50 μm in diameter), similar tubular structures ex gr. *Siphonophycus* (55–56 μm wide) with weak transverse ornamentation, and aggregates of polytrichome *Eomicrocoleus* (separate envelopes 1–2 μm wide, and aggregates up to 70 μm wide). These forms are accompanied by very large trichome-like structures (up to 90 μm wide) previously unknown and representing thin filaments transparent under microscope and composed of elongated cells each up to 20–22 μm wide and to 50–60 μm long (probably remains of ancient siphonocladacean green algae *Proterocladus*). Intricate microfossils are represented by trilobate *Majaphyton* thalluses (up to 120–200 μm), rare dark filaments dichotomously branching and resembling *Pseudodendron* (20 μm wide), and by irregular envelopes of *Caudosphaera* with a single long projection (cells are 70–80 μm in diameter and projection, up to 100 μm long).

The second level (interval from 158–160 to 162–164 m above the base of the subformation) yielded an impoverished assemblage including rare acritarchs *Leiosphaeridia* (40 μm in diameter), colonial coccoidal *Myxococcoides* (cell diameter is 10–12 μm), filamentous envelope of *Leiotrichoides* (18–20 μm wide), and wide taeniate structures with clear transverse ornamentation (60 μm wide).

The third level (interval from 170–172 to 178–180 m above the base of the subformation) encloses the most representative assemblage of Nugush microfossils. The latter includes abundant acritarchs *Leiosphaeridia* (80 to 260 μm in diameter), less common *Chuaria* (up to 320–340 μm), fringed *Simia* (external diameter to 200 μm), *Nucellosphaeridium* vesicles with internal bodies (20–22 μm), *Pterospermopsimorpha* (140 μm), and oval *Navifusa* (110–130 × 180–200 μm). Colonial coccoidal microfosssils are less abundant than acritarchs and include only *Myxococcoides* fragments (cells are up to 30 μm in diameter) and chain colonies of *Polysphaeroides* (cells are 3–4 μm in diameter, chains up to 10 μm long).

Filamentous morphotypes represent, along with acritarchs, dominant components of the assemblage from the third level. In addition to *Eomycetopsis, Leiotrichoides*, and *Asperatofilum* inherited from underlying microbiotas and similar in dimensions, the assemblage includes three very peculiar tubular morphotypes: (1) thin-walled structures (60 to 80–84 μm) barren of any noticeable ornamentation or having an indistinct transverse striation and resembling *Taenitrichoides*; (2) microfossils with thicker walls and distinct transverse ornamentation comparable with *Plicatidium* (to 88–90 μm); and (3) very dense cuticle-like tubular structures having well-developed transverse ornamentation and comparable with *Rectia* (44–50 μm). Trichome-like structures resembling very large *Botuobia* are close to the second morphotype by their dimensions (from 60 to 90 μm). Microfossils of intricate structures include wide dark thalluses (80–90 μm wide), *Caudosphaera* vesicles with projection (vesicle diameter to 60–90 μm, projection more than 100 μm long), fragments of large elongated–ellipsoidal bodies morphologically close to *Lakhandinia* (90 × 200 μm), and fusiform structures with enclosed interwoven thin filaments (40–120 μm, filaments are 1–2 μm wide). Biological nature of two latter morphotypes is unclear as yet.

The Lemeza Subformation. Microfossils are confined to several thin (several centimeters) dark siltstone layers alternating with thicker (from dozens of centimeters to several meters) beds in the 45-m-thick interval localized close to the subformation top. Taxonomic diversity of relevant assemblage is lowest as compared to all others considered above. It includes only rare acritarchs *Leiosphaeridia* (including *L. bicrura* and

L. ternata) up to 20–64 μm in size, *Nucellosphaeridium* (20 μm), *Satka* (40 μm), single colonial coccoidal *Myxococcoides* (cells are to 30 μm in diameter), and simplest sheaths of *Eomycetopsis* (4 μm wide).

Thus, our study divulged the representative Nugush microbiota (23 species and 23 genera of microfossils) in pre-Bederysh deposits of the Zil'merdak Formation, whose microphytological characteristic was limited only by single poorly preserved Bir'yan and Nugush acritarchs mentioned by Yankauskas (1982) and Kozlova *et al.* (1994). We also discovered for the first time the Lemeza microfossils (5 genera and 6 species). Both of these microbiotas are of particular interest, because they cover an important gap in the paleontological characteristic of the Riphean stratotype. In practice, however, only the Nugush microfossils having a high stratigraphic potential can be used for intra- and interregional correlation. Comparison of all microbiotas characterized above and their position in the general succession of Late Precambrian microfossils are considered below.

DISCUSSION

The data considered above characterize six Riphean microbiotas of the Urals region, namely the Kyrpy (Pal'niki), Kuzha (Nizhnyaya Kuzha and Urtino), Tyul'men, Nugush, and Lemeza assemblages. The latter consisting only of several transitional acritarch taxons and colonial coccoidal vesicles and sheaths is excluded from further discussion. Amid five others, the abundant Kuzha and Nugush microbiotas are first described in detail. In contrast, only few new characteristics were added to the richest Pal'niki microbiota that was known as including large and intricate forms unusual for this Riphean level in the Urals region. As for Tyul'men microbiota, new materials only slightly extended the known list of its microfossils, but significantly specified their stratigraphic distribution in the bed succession.

New data on the Nugush microbiota confined to the lower part of the Karatavian in its type section elucidate paleontological characteristics of this interval and lead to a very important biostratigraphic conclusion, which can be formulated in the following way. The Nugush beds enclose several characteristic forms unknown in the Avzyan (including Revet) layers proper and in underlying strata of the southern Urals. These forms are *Chuaria, Navifusa, Polysphaeroides, Ostiana, Majaphyton, Rectia, Taenitrichoides Plicatidium, Caudosphaera*, diverse and very wide filamentous sheaths and trichome-like structures, as well as intricate morphotypes. Finds of these forms below the Bederysh beds clearly indicate that there is, in addition to the previously known pre-Muldakaevo level, another one post-Yurmatinian level of very important changes in microbiota composition recorded in the Riphean type section of the southern Urals. This Kabakovo microphytological level (it should be remembered that its name has nothing to do with the synonymous lithostratigraphic unit) was originally distinguished by Yankauskas (Keller and Yankauskas, 1980; Yankauskas, 1982), who analyzed at that time only limited data on the Tukaevo–Akberdino (Ol'khovka) successions penetrated by Borehole Kabakovo-62 in Bashkortostan. Yankauskas conditionally correlated the pre-Kabakovo level with the Bir'yan interval of the Upper Riphean type section, i.e., he placed it at the base of the Karatavian.

The reality and interregional significance of this or closely located boundary is more distinctly expressed in the representative succession of microfossils in the Siberian hypostratotype of the Riphean in the Uchur–Maya region (pre-Kerpyl' level), and necessity for searching its analogues in the southern Urals was repeatedly stressed earlier (Veis, 1988, 1993; Pyatiletov, 1988; Golovenok and Belova, 1994, 1995; Semikhatov, 1995; and others). However, objective data elucidating the general biostratigraphic significance of this level appeared only now. In the light of these new data, the presence of almost identical stratigraphically important forms of the representative Nugush microbiota from the southern Urals and of the Kerpyl' (Totta) microbiota from the Uchur–Maya region (and of the Bezymyannyi microbiota from the Turukhansk uplift reliably correlated with the latter) demonstrate their mutual similarity. The microphytological specificity of three above microbiotas is obvious, because they all significantly differ from microfossils characterizing older strata of the Yurmatinian Group that represents the Middle Riphean stratotype (*Stratotip rifeya...*, 1982) and the Aimchan deposits of the Uchur–Maya region, which are unanimously correlated with that group (Veis, 1988; Sergeev, in press). In other words, new data on taxonomic composition of the Nugush microbiota are consistent with the idea of the Kabakovo level individualization and yield the reliable biostratigraphic basis supporting earlier assumptions that the Kerpyl' and Bezymyannyi deposits of Central Siberia accumulated in the post-Yurmatinian time (Khomentovskii *et al.*, 1985; Komar, 1990; Veis *et al.*, 1998)

It should be emphasized that substantial transformations in microbiotas of the southern Urals are manifested in all main morphological groups of the Nugush assemblage, and their rank is identical or probably higher than that of changes in the Precambrian microbiotas previously established at the higher pre-Bederysh (Muldakaevo) level of the Riphean stratotype. Precisely the forms listed above as distinctive taxons of the Nugush assemblage were mentioned amid most important microorganisms characterizing evolutionary innovations in the Upper Riphean Muldakaevo microbiota. In the latter, they embody, along with other key constituents (*Chauria, Trachyhystrichosphaera, Tortunema, Polytrichoides, Pellicularia, Chlorogloeaopsis, Arctacellularia*, and others), the turning point in the history of the Riphean biota (Yankauskas, 1982) termed now as "Neoproterozoic revolution" (Knoll and

Sergeev, 1995; and others). Our data on the earlier appearance of some characteristic Muldakaevo forms in the southern Urals by no means impair the paleobiological significance and biostratigraphic potential of pre-Bederysh reorganization in the Riphean communities of organisms, which is manifested by presence of aforementioned taxons in association with other intricate morphotypes (*Segmentothallus, Rugosoopsis, Mucorites, Majasphaeridium, Jacutianema, Fabiformis*, and others) at the Lakhanda, Derevnya, and some other microphytological levels of Central Siberia correlated with that of the Bederysh assemblage (Pyatiletov, 1988; German, 1990; and others). Simultaneously, these data clearly indicate that the reorganization was more durable than it was assumed earlier and developed in a more complex multistage manner (Veis *et al.*, 1998).

Taking significant differences between the Karatavian (including Nugush) and Burzyanian–Yurmatinian (including Revet) microfossils from the Riphean type section as the reference point, let us try to estimate position of the Tyul'men and two Kuzha microbiotas, whose stratigraphic status is debatable, in the general succession. First, it should be noted that the indicated microbiotas are close, but not identical in taxonomic composition. All of them include abundant transitory acritarchs *Leiosphaeridia* (the characteristic Nizhnyaya Kuzha–Tyul'men level, where small *Leiosphaeridia* are sharply preponderant, inclusive) coexisting with *Myxococcoides, Eomycetopsis, Leiotrichoides, Oscillatoriopsis, Germinosphaera*, and also with *Ostiana* thalluses and serial *Sphaerocongregus*, which have narrower stratigraphic ranges. In addition to mentioned forms, every of the considered microbiotas includes more intricate, stratigraphically important morphotypes. These are acritarchs *Valeria* and *Navifusa*, filamentous *Asperatofilum* and *Polytrichoides*, and large ellipsoidal *Brevitrichoides* from the Tyul'men microbiota, wide *Siphonophycus* sheaths with transverse ornamentation and taeniate *Taenitrichoides* from the Urtino Formation, and also branching thalluses ex gr. *Pseudodendron* from the Nizhnyaya Kuzha Formation.

Most remarkable Tyul'men and Kuzha microfossils of the southern Urals occur as well in Karatavian microbiotas (including the Nugush one), but they are missing from the Burzyanian and Yurmatinian assemblages. Similar situation is typical of microfossils distribution throughout the Riphean reference sections of the Uchur–Maya and Turukhansk regions, where the listed forms (taking into consideration *Chuaria* replacing Uralian *Valeria* in Siberia) represent an important component of the Kerpyl and Bezymyannyi assemblages, being missing from the older Aimchan and Uchur groups of the first region (Veis, 1988; Veis *et al.*, 1998; Pyatiletov, 1988; Sergeev, in press). It is tempting to consider this fact as a decisive argument supporting earlier inferences about correlation of Tyul'men and, partly, Kuzha deposits between each others, their closeness to the Karatavian level, and, consequently, independence with regard to the Yurmatinian one (as far as it concerns the Kerpyl' and Bezymyannyi microbiotas of central Siberia, such a step has no alternative in fact).

Being attractive from the biostratigraphic standpoint, this resolution of the issue contradicts the traditional concept of Uralian geologists, who correlate the Kuzha strata with the lower or middle Avzyan beds (or even with the Zigaza–Komarovo Formation) and consider the Tyul'men succession as an equivalent of the upper Avzyan deposits (Larionov, 1994; Kozlov *et al.*, 1997; Maslov, 1997; and others). In this case, the listed characteristic Kuzha–Tyul'men morphotypes characterizing exclusively the Karatavian type microbiotas turn into transitory assemblage not only for the greater part of the Yurmatinian, but also, as we will see further, for the entire Riphean, if relevant data on northern Siberia are taken into consideration (Sergeev *et al.*, 1995; Knoll and Sergeev, 1995; Semikhatov, 1995; 1997).

Such a radical conclusion repudiating almost all biostratigraphic experience of Upper Precambrian microphytology is inconsistent with new data obtained for the Pal'niki microbiota of the Urals region, which is spatially separated from others known in the southern Urals. We should remind here that many researchers correlate deposits enclosing this most representative microbiota even with pre-Yurmatinian strata on the basis of geophysical data. Simultaneously, the microbiota in question is very diverse in composition and includes very many characteristic Karatavian morphotypes elucidating its position in the general succession of Riphean microfossils in the southern Urals more reliably than in the case of impoverished Tyul'men and Kuzha assemblages.

Stratigraphically important taxons of the Pal'niki microbiota are acritarchs *Valeria* discovered by Kozlova (1990) and *Chuaria, ?Prolatoforma, Simia, Navifusa, Spumosina*, colonial coccoidal *Ostiana*, taeniate *Asperatofilum*, multiserial *Polytrichoides*, ornamented tubular *Siphonophycus*, elongated–ellipsoidal *Brevitrichoides*, cuticular *Rectia* and *Plicatidium*, wide filamentous *Palaeolyngbya sphaerocephala* Herm. et Pyl., giant trichomes and trichome-like structures, intricate *Pellicularia, Caudosphaera* forms having long projection, filaments ex gr., *Pseudodendron* with longitudinal ornamentation, and largest of branching *Archaeoclada* thalluses.

In the Riphean stratotype section of the Bashkirian meganticlinorium, most of these and close forms (with due account for changes in classification of Precambrian microfossils; Yankauskas *et al.*, 1989) occur only in the Zil'merdak (Nugush and Bederysh) and post-Zil'merdak (Inzer and Uk) successions of the Karatavian age (Yankauskas, 1982; Veis *et al.*, 1990; Kozlova, 1990, 1994; Mikhailova and Podkovyrov, 1992; Kozlov *et al.*, 1993). In the Nugush microbiota confined to the lower part of the Zil'merdak Formation, these forms are

represented by *Chuaria, Navifusa, Ostiana, Asperatofilum*, ornamented tubular *Rectia* and *Plicatidium*, and many wide trichomes and trichome-like structures known from the Pal'niki assemblage. The overlying Muldakaevo microbiota from the upper Zil'merdak Formation is close to the latter, because it represents association of characteristic Nugush forms inherited form underlying strata with lophostriated *Valeria, Polytrichoides* sheaths occurring in both microbiotas, filmy fusiform *Pellicularia*, and elongated–ellipsoidal *Brevitrichoides bashkiricus* Jank. In the Shishenyak microbiota of the Inzer Formation and in the Uk microbiota from the synonymous formation (it should be noted that the latter includes only taxons inherited from underlying deposits), companions of listed forms are large marginate acritarchs *Simia*, ellipsoidal *?Prolatoforma* with bipolar projections, spongy *Spumosina*, and others.

Thus, the listed key taxons of the Pyl'niki (Kyrpy) microbiota reveal its taxonomic affinity only with Karatavian microbiotas of the Riphean stratotype (first of all, with the Nugush, Muldakaevo, and, to a certain extent, even with the Shishenyak and Uk assemblages), but not with microfossils characterizing the Burzyanian and Yurmatinian intervals proper (when the Tyul'men and Kuzha deposits, whose stratigraphic position is debatable, are excluded from the latter). Yankauskas (1982) and, particularly, Kozlova (1990), who stressed inconsistency between microphytological and all other age estimates for Riphean successions in the southern Urals and adjacent region, were of the same opinion.

Other, first of all microphytological data on the Riphean deposits in central and northern Siberia slightly mitigates the categorical character of conclusion about the Late Riphean (i.e., Karatavian proper) age of the Pal'niki (and similarly of Kuzha and Tyul'men) microfossil assemblages. As was noted, many of taxons known from the southern Urals and adjacent regions, e.g., *Chuaria, Simia, Ostiana, Polytrichoides, Rectia, Asperatofilum, Archaeoellipsoides (=Brevitrichoides), Caudosphaera*, large branching thalluses, and some other forms typical of the Tyul'men and Kuzha beds, are also widespread in the Bezymyannyi–Sukhaya Tunguska succession of the Turukhansk uplift and in the Kerpyl' strata of the Uchur–Maya area of central Siberia (Pyatiletov, 1988; Veis and Petrov, 1994; Veis *et al.*, 1998; Petrov *et al.*, 1995; and others). Based on different criteria, some researchers refer now these deposits of central Siberia to the upper part of the Middle Riphean, whereas others place them in the lower part of the Upper Riphean (Semikhatov and Serebryakov, 1982; Khomentovskii *et al.*, 1985; Shenfil', 1991; Semikhatov, 1995; 1997), and only second conclusion appears to be valid from the microphytological standpoint. At the same time, acritarchs *?Prolatoforma, Navifusa*, and intricate branching thalluses *Archaeoclada* occurring in the Pal'niki microbiota are recorded in the above-mentioned areas of central Siberia at the undoubtedly Upper Riphean level of the Derevnya and Lakhanda microbiotas, whereas characteristic ornamented filaments *Palaeolyngbya sphaerocephala* Herm. et. Pyl. and thalluses ex gr. *Pseudodendron* first appear there even at the higher Miroedikha level of the Karatavian (German, 1990; Petrov and Veis, 1995; Veis *et al.*, 1998). Thus, despite some uncertainties related to ambiguous position of the Middle–Upper Riphean boundary in Siberia, the whole assemblage of morphotypes characterizing the Pal'niki and close Kuzha and Tyul'men microbiotas is recorded there only in deposits of the Upper Riphean Erathem.

Situation becomes more ambiguous, when the Pal'niki microbiota of the Urals region is compared with organic-walled microfossils from the Riphean sequences of the western slope of the Anabar massif in northern Siberia (Veis and Petrov, 1994). The Ust-Il'ya and Kotuikan formations corresponding here to the middle part of the Riphean enclose abundant and diverse microfossils. Their assemblages include all principal morphotypes of the Pal'niki assemblage, except for the "youngest" representatives of the latter, such as *?Prolatoforma, Navifusa, Spumosina, Palaeolyngbya sphaerocephala* Herm. et Pyl., Pseudodendron, and some new forms. The affinity of north Siberian microbiotas with the Upper Riphean (Kerpyl' and, partly, Lakhanda, as well as their analogues) microfossil assemblages of the southern Urals and central Siberia was repeatedly emphasized in earlier works (Veis and Petrov, 1994; Veis *et al.*, 1998; and others). This conclusion is, however, inconsistent with data on the Kotuikan stromatolites, among which several characteristic Lower Riphean forms were identified in addition to preponderant Siberian endemic species (Komar, 1966; Krylov, 1975), and also with K–Ar and Rb–Sr isochron dates for glauconite (1465 and 1491 Ma, respectively) and illite (1430 Ma) from the Ust-Il'ya Formation, two first interpreted as corresponding to the early diagenesis time and next one as a time of the subsidence diagenesis (Gorokhov *et al.*, 1991; 1997). This interpretation is compatible with Rb–Sr isochron dates for two different phases of authigenic illite from the overlying Yusmastakh Formation. The geologically older phase yielded the age value of 1270 ± 8 Ma, and the younger one was dated back to 1190 ± 10 Ma (Gorokhov *et al.*, 1998). The first phase could originate during the subsidence diagenesis and second one during the regressive catagenesis at the stage of uplift. The situation with age discrepancies becomes aggravated further, when chemostratigraphic data are taken into consideration (Pokrovskii and Vinogradov, 1991; Gorokhov *et al.*, 1995; Knoll *et al.*, 1995). Pokrovskii and Vinogradov, who measured the uniform and very low initial $^{86}Sr/^{87}Sr$ ratios (0.7045–0.7050) in the entire pre-Staraya Rechka part of the Anabar section, interpreted them as a probable evidence for the Early Proterozoic age of studied deposits. In contrast, other researchers argue for correspondence of these ratios to those measured in the Lower and Middle Riphean (according to their viewpoints) deposits in the adjacent regions (Gor-

okhov *et al.*, 1995). Gorokhov and his co-authors believe that the Sr isotope composition in carbonate rocks of the Anabar section indicates only their pre-Vendian age, because close $^{86}Sr/^{87}Sr$ ratios were established for the Inzer Formation of the Upper Riphean type succession in the Urals and for the undoubtedly Upper Riphean Lakhanda Group of the Uchur–Maya region (0.70525–0.70538 and 0.70519–0.70550, respectively; Kuznetsov *et al.*, 1997; Semikhatov *et al.*, 1998). Consequently, according to secular variations of initial $^{86}Sr/^{87}Sr$ ratios in the Precambrian, their low values characterizing the Anabar section suggest only the ambiguous conclusion that rock ages may span here the interval from the Early Proterozoic to the Late Riphean. Data on carbon isotope systematics do not simplify the situation, because C-isotope chemostratigraphic markers obtained for carbonates of the Anabar uplift (Knoll *et al.*, 1995) are equally characteristic of the pre-Riphean (Knoll *et al.*, 1995; Semikhatov, 1995, 1997) and Upper Riphean (Khomentovskii *et al.* 1985; and others) deposits.

In conclusion, the following can be postulated. Representative microphytological data suggest that the Kuzha, Tyul'men, and Kyrpin successions should be referred to the post-Yurmatinian interval of the Riphean. Judging from these data, the idea to place these successions at the level of the pre-Karatavian hiatus in the southern Urals and even to correlate them partially with the Karatavian type section is not only possible, but highly plausible. Moreover, the Pal'niki microbiota recorded far away from the Riphean stratotype is very specific in micropytological aspect and could have a higher stratigraphic position in the post-Yurmatinian interval as compared with that of the Kuzha and Tyul'men microbiotas despite some statements suggesting the reversed relationships. The general contradictory situation in the Upper Precambrian stratigraphy related to discrepancies in data obtained by different methods (Xiao *et al.*, 1997) leaves open the issue concerning the true chronological relationships between the Pal'niki, Tyul'men, Kuzha, and type Riphean microboiotas.

CONCLUSION

Thus, the analysis of representative rock samples from the Middle–Upper Riphean boundary deposits of the Riphean type section on the southern Urals revealed abundant microfossils and elucidated microphytological characteristic of ancient strata in the Volga–Urals region perspective with respect to oil and gas deposits. In total, six microbiotas of different abundance and diversity, which include more than two dozens of genera and species of organic-walled microfossils, are established in both regions. These are the Kuzha (Nizhnyaya Kuzha and Urtino), Tyul'men, Nugush, and Lemeza microbiotas of the Bashkirian meganticlinorium and Pal'niki microbiota of the Kama–Belaya aulacogen. The results obtained suggest the following main conclusions.

(1) The Nugush microbiota from the lower part of the Karatau Group shows principal taxonomic differences from older Yurmatinian and Burzyanian microbiotas of the Riphean stratotype and includes characteristic morphotypes widespread only at high levels of the group. At the next younger Muldakaevo (Bederysh) level, these morphotypes coexist with several other remarkable forms. This peculiarity in microfossil distribution suggest that there are at least two important levels in the lower part of the Upper Riphean microphytological succession in the Riphean stratotype.

(2) Both mentioned levels can be reliably traced in representative Riphean sections of Siberia (the pre-Kerpyl' and pre-Lakhanda levels distinct in the Uchur–Maya and other central areas and less expressed in northern section). They have a potential for interregional correlation and suggest, for the first time, a real opportunity of using microphytological data for detailed biostratigraphic typification of the Middle–Upper Riphean boundary. However, realization of this potential may change definition of the Upper Riphean boundary in its stratotype, where it is formally placed now at the base of the Zil'dermak Formation of the Karatau Group thus having a historical–geological substantiation in terms of chronostratigraphy (Semikhatov *et al.*, 1991; *Postanovlenie...*, 1993).

(3) Microbiotas from the Kuzha and Tyul'men deposits of the southern Urals, stratigraphic position of which is debatable, reveal an impoverished taxonomic composition as compared with the Nugush and Bederysh microbiotas. At the same time, they include several characteristic Upper Riphean forms also reported from the Lower and Middle Riphean type sections of the Bashkirian meganticlinorium. These specific microfossils of the Kuzha and Tyul'men assemblages can be considered as an indirect argument in favor of the assumption that the accumulation time of their host deposits corresponds to the long-lasted hiatus separating the Yurmatinian and Karatau groups in the Riphean stratotype.

(4) The previous conclusion is also compatible with new data on taxonomic composition of the representative Pal'niki microbiota from the Kama–Belaya aulacogen section. This microbiota characterizes deposits occurring, according to recent correlation schemes, substantially below the Kuzha and Tyul'men beds, and has peculiar taxonomic composition very similar to that of younger (post-Nugush, post-Kerpyl', and others) microbiotas of the southern Urals and central Siberia and does not preclude reversed relationships of the Pal'niki microbiota with the Kuzha and Tyul'men microfossil assemblages.

ACKNOWLEDGMENTS

We express our sincere gratitude to M.A. Semikhatov for his attention to our work and for fruitful discussion of the results obtained. The work could not be performed without assistance of V.I. Kozlov, P.N. Mikhailov, and N.D. Sergeeva in our field investigations and in defining stratigraphic position of examined samples. We are also grateful to V.A. Filippov for professional clarification of most complicated issues of the regional Riphean stratigraphy of the southern Urals. Thorough reviews of A.V. Maslov and M.S. Yakshin substantially improved our manuscript and formulated concepts. The work was supported by the Russian Foundation for Basic Research (projects 98-05-64858 and 99-05-64054) and by the Uralian Project of the Geological Institute RAS.

Reviewers A.V. Maslov and M.S. Yakshin

REFERENCES

Aliev, M.M., Morozov, S.G., Postnikova, I.E., *et. al., Geologiya i neftegazonosnost' rifeiskikh i vendskikh otlozhenii Volgo-Ural'skoi provintsii* (Geology and Oil-and-Gas Resources of the Riphean–Vendian Deposits in the Volga–Urals Province), Moscow: Nedra, 1977.

Andreev, Yu.V., Ivanova, T.V., Keller, B.M., *et al.*, Upper Proterozoic Stratigraphy of the Russian Plate Margin and Western Slope of the Southern Urals, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1981, no. 10, pp. 57–67.

Butterfield, N.J., Knoll, A.H., and Swett, K., Paleobiology of the Neoproterozoic Svanbergfiellet Formation, Spitsbergen, *Fossil and Strata*, 1994, no. 15, pp. 1–84.

Filippov, V.A., Lithological Complexes of the Bashkirian Meganticlinorium and Their Metallogeny, *Dokl. Akad. Nauk SSSR*, 1983, vol. 271, no. 4, pp. 935–938.

Filippov, V.A., The Kuzha Group and Paleotectonic Conditions of Its Formation, *Rifei Severnoi Evrazii. Geologiya. Obshchie problemy stratigrafii* (The Riphean of Northern Eurasia: Geology and General Problems of Stratigraphy), Yekaterinburg: Ural. Otd. Ross. Akad. Nauk, 1997, pp. 191–201.

German, T.N., *Organicheskii mir milliard let nazad* (Organic World a Billion Years Ago), Leningrad: Nauka, 1990.

Golovenok, V.K. and Belova, M.Yu., "Gigantism" in Precambrian Microfossils and Its Biostratigraphic Significance, *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 6, pp. 33–39.

Golovenok, V.K. and Belova, M.Yu., Microfossils in the Precambrian Biostratigraphy: Methodical Problems of Study and Practical Utilization, *Reg. Geol. Mineral.*, St. Petersburg, 1995, no. 4, pp. 63–75.

Gorokhov, I.M., Semikhatov, M.A., Drubetskoi, E.R., *et al.*, Rb–Sr and K–Ar Age of Sedimentary Geochronometers: the Lower Riphean of the Anabar Massif, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1991, no. 7, pp. 17–32.

Gorokhov, I.M., Semikhatov, M.A., Drubetskoi, E.R., *et al.*, Rb–Sr Systematics of Pelitic Fractions from the Lower Riphean Shales, the Ust'-Il'ya Formation, Anabar Massif, Northern Siberia, *Litol. Polezn. Iskop.*, 1997, no. 5, pp. 530–539.

Gorokhov, I.M., Semikhatov, M.A., Turchenko, T.L., *et al.*, Rb–Sr Systematics of Middle Riphean Shales, the Yusmastakh Formation, Anabar Massif, Siberia, *ICOG-9, Abstracts, Chinese Sci. Bull.*, Beijing, 1998, vol. 43. Supplement., August, p. 47.

Keller, B.M. and Yankauskas, T.V., Microfossils from the Riphean Stratotype of the Southern Urals, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1980, no. 12, pp. 58–67.

Keller, B.M., Semikhatov, M.A., and Chumakov, N.M., Typical Sections of the Upper Proterozoic Erathem of the Proterozoic, *27-i Mezhdunarodnyi geologicheskii kongress. Doklady* (Proc. 27th International Geological Congress. Papers), Moscow: Nauka, 1984, vol. 5, pp. 56–76.

Khomentovskii, V.V., Shenfil', V.Yu., and Yakshin, M.S., The Riphean of the Siberian Platform, *Geol. Geofiz.*, 1985, no. 7, pp. 25–33.

Knoll, A.H. and Sergeev, V.N., Taphonomic and Evolutionary Changes Across the Mezsoproterozoic-Neoproterozoic Transition, *N. Jhrb. Palaeontol., Abh.*, 1995, vols. 1–3, pp. 289–302.

Knoll, A.H., Sweet, K., and Mark, J., Paleobiology of a Neoproterozoic Tidal Flat, Lagoonae the Dracen Conglomerate Formation, Spitsbergen, *J. Paleontol.*, 1991, vol. 65, no. 4, pp. 531–570.

Knoll, A.H., Kaufman, A.J., and Semikhatov, M.A., *The Carbon-Isotopic Composition of Proterozoic Carbonates*, Riphean successions from northwestern Siberia (Anabar Massif Turukhansk Uplift), *Amer. J. Sci.*, 1995, vol. 295, pp. 823–850.

Kozlov, V.I., *Verkhnii rifei i vend Yuzhnogo Urala* (The Upper Riphean and Vendian of the Southern Urals), Moscow: Nauka, 1982.

Kozlov, V.I., The Riphean Stratotype of the Southern Urals, *Stratigrafiya, litologiya i geokhimiya verkhnego dokembriya Yuzhnogo Urala i Priural'ya* (Stratigraphy, Lithology, and Geochemistry of the Upper Precambrian of in the Southern Urals and Cis-Urals), Ufa: Bashkir. Fil. Akad. Nauk SSSR, 1986, pp. 6–16.

Kozlov, V.I., Problems of the Upper Precambrian in the Southern Urals, *Verkhnii dokembrii Yuzhnogo Urala i Vostoka Russkoi plity* (The Upper Precambrian of the Southern Urals and Eastern Russian Plate), Ufa: Ural. Nauch. Tsentr Ross. Akad. Nauk, 1993, pp. 4–13.

Kozlov, V.I., Sergeeva, N.D., Larionov, N.N., *et al.*, The Upper Precambrian of the Southern Urals and Adjacent Regions of the Eastern Russian Plate, *Rifei Severnoi Evrazii. Geologiya. Obshchie problemy stratigrafii* (The Riphean of Northern Eurasia: Geology and General Problems of Stratigraphy), Yekaterinburg: Ural. Otd. Ross. Akad. Nauk, 1997, pp. 85–93.

Kozlov, V.I., Veis, A.F., Sergeeva, N.D., *et al.*, Lithologoical–Petrographical Characteristics and Microfossils the Upper Precambrian Deposits: The Azino-Pal'niki Parametric Hole 133 in Udmurtiya, *Ezhegodnik-96. Informatsionnye materialy* (Informational Materials of 1996), Yekaterinburg: Ural. Otd. Ross. Akad. Nauk, 1998, pp. 63–70.

Kozlova, E.V., Microfossils of from the Avzyan Formation of the Middle Riphean in the Southern Urals, *III Vsesoyuz. simpozium po paleontologii dokembriya i rannego kembriya* (Abstracts, III All-Union Symposium on Paleontology of the Precambrian and Early Cambrian. Abstracts of Papers), Petrozavodsk: Karel'sk. Filial Akad. Nauk SSSR, 1987, pp. 46–47.

Kozlova, E.V., Findings of Microfossils in the Riphean Deposit of the Eastern Russian Plate, *Geologiya dokembriya Yuzhnogo Urala i vostoka Russkoi plity* (Geology of the Precambrian in the Southern Urals and Eastern Russian Plate), Ufa: Bashkir. Nauch. Tsentr, Ural. Otd. Akad. Nauk SSSR, 1990, pp. 50–56.

Kozlova, E.V., Organic-Walled Microfossils from Deposits of the Avzyan Formation of the Southern Urals, *Verkhnii dokembrii Yuzhnogo Urala i Vostoka Russkoi plity* (The Upper Precambrian of the Southern Urals), Ufa: Ural. Nauch. Tsentr Ross. Akad. Nauk, 1993, pp. 60–68.

Komar, V.A., *Stromatolity verkhnedokembriiskikh otlozhenii severa Sibirskoi platformy i ikh stratigraficheskoe znachenie* (Stromatolites from Upper Precambrian Deposits of Northern Siberian Platform), Moscow: Nauka, 1966.

Komar, V.A., Stromatolites and Correlation of the Riphean Reference Sections in Siberia and the Urals, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1990, no. 10, pp. 30–35.

Krylov, I.N., *Stromatolity rifeya i fanerozoya SSSR* (Riphean and Phanerozoic Stromatolites of the USSR), Moscow: Nauka, 1975, *Tr. Geol. Inst. Akad. Nauk SSSR*, 1975, no. 274.

Kuznetsov, A.B., Gorokhov, I.M., Mel'nikov, N.N., *et al.*, Sr Isotopes in Limestones of the Karatau Group, the Southern Urals, *Rifei Severnoi Evrazii. Obshchie problemy stratigrafii* (The Riphean of Northern Eurasian and General Problems of Stratigraphy), Yekaterinburg: Ural. Otd. Ross. Akad. Nauk, 1997, pp. 182–186.

Larionov, N.N., Geology and Ore-Bearing Potentials of the Avzyan Terrigeneous–Carbonate Formation of the Middle Riphean, *Extended Abstract of Cand. Sci. (Geol.–Mineral.) Dissertation*, Yekaterinburg: Inst. Geol. Geophys. Ural. Div. Ross. Acad. Nauk, 1994.

Maslov, A.V., *Osadochnye assotsiatsii rifeya stratotipicheskoi mestnosti (evolyutsiya vzglyadov na usloviya formirovaniya, litofatsial'naya zonal'nost')* (Main Sedimentary Associations of the Riphean Stratotype: Evolution of Views on the Formation Conditions and Lithofacies Zoning), Yekaterinburg: Inst. Geol. Geofiz. Ural. Otd. Ross. Akad. Nauk, 1997.

Maslov, A.V. and Isherskaya, M.V., *Osadochnye assotsiatsii rifeya Volgo-Ural'skoi oblasti (usloviya formirovaniya i litofatsial'naya zonal'nost')* (Riphean Sedimentary Associations in the Volga–Urals Region: Formation Conditions and Lithofacies Zoning), Yekaterinburg: Ural. Nauch. Tsentr, Ural. Otd. Ross. Akad. Nauk, 1998.

Mikhailov, P.N., Principal Paleomagnetic Features of the Avzyan Formation of the Bashkirian Meganticlinorium, *Stratigrafiya i litologiya verkhnego dokembriya Yuzhnogo Urala i Priural'ya* (Upper Precambrian Stratigraphy and Lithology of the Upper Precambrian in the Southern Urals), Ufa: Bashkir. Filial Akad. Nauk SSSR, 1983, pp. 3–11.

Mikhailova, N.S. and Podkovyrov, V.N., New Data on Organic-Walled Microfossils from Upper Precambrian Deposits of the Urals, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1992, no. 10, pp. 111–123.

Morozov, S.G. and Revenko, E.A., On the Age of Carbonate Rocks of the Bavly Formation, *Dokl. Akad. Nauk SSSR*, 1969, vol. 148, no. 4, pp. 159–162.

Ozhiganova, L.D., The Lower Riphean of Western Bashkiriya, *Stratigrafiya i litologiya verkhnego dokembriya i paleozoya Yuzhnogo Urala i Priural'ya* (Stratigraphy and Lithology of the Upper Precambrian and Paleozoic in the Southern Urals and Cis-Urals), Ufa: Bashkir. Filial Akad. Nauk SSSR, 1983, pp. 33–39.

Petrov, P.Yu. and Veis, A.F., Facies–Ecological Structure of the Derevnya Formation Microbiota: Upper Riphean, Turukhansk Uplift, Siberia, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 5, pp. 13–40.

Petrov, P.Yu., Semikhatov, M.A., and Sergeev, V.N., Development of the Riphean Carbonate Platform and Distribution of Silicified Microfossils: The Sukhaya Tunguska Formation, Turukhansk Uplift, Siberia, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 6, pp. 79–89.

Plumb, K.A., New Precambrian Time Scale, *Episodes*, 1991, vol. 14, no. 2, pp. 139–140.

Pokrovskii, B.G. and Vinogradov, V.I., Isotopic Composition of Strontium, Oxygen, and Carbon in the Upper Precambrian Carbonates from the Western Slope of the Anabar Uplift (Kotuikan River), *Dokl. Akad. Nauk SSSR*, 1991, vol. 320, no. 5, pp. 1245–1250.

Postanovlenie po obshchei stratigraficheskoi shkale dokembriya SSSR. Postanovlenie MSK i ego postoyannykh komissii (Resolution on the General Stratigraphic Scale of the Precambrian in the USSR. Resolutions of ISC and Its Permanent Commissions), St. Petersburg: Vses. Geol. Inst., 1993, no. 26.

Pyatiletov, V.G., Microfossils of the Late Precambrian from the Uchur–Maya Region, *Pozdnii dokembrii i rannii paleozoi Sibiri. Vend i rifei* (The Late Precambrian and Early Paleozoic of Siberia: The Vendian and Riphean), Novosibirsk: Inst. Geol. Geofiz., Sib. Otd. Akad. Nauk SSSR, 1988, pp. 47–94.

Schatsky, N.S., *Ocherki tektoniki Volgo-Ural'skoi neftenosnoi oblasti i smezhnoi chasti zapadnogo sklona Yuzhnogo Urala* (Tectonics of the Volga–Urals Petroliferous Region and Adjacent Western Slope of the Southern Urals), Moscow: Mosk. O–vo Ispyt. Prir., 1945.

Semikhatov, M.A., General Subdivision of the Precambrian: Comparison of the Latest Scales, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 1, pp. 6–20.

Semikhatov, M.A., Methodical Principles of the Riphean Stratigraphy, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 6, pp. 50–67.

Semikhatov, M.A., Methods of Subdivision and Correlation of the Riphean: Modern Assessment, *Rifei Severnoi Evrazii. Geologiya. Obshchie problemy stratigrafii* (The Riphean of Northern Eurasia: Geology and General Problems of Stratigraphy), Yekaterinburg: Ural. Otd. Ross. Akad. Nauk, 1997, pp. 3–13.

Semikhatov, M.A. and Serebryakov, S.N., *Sibirskii gipostratotip rifeya* (Siberian Hypostratotype of the Riphean), Moscow: Nauka, 1983.

Semikhatov, M.A., Shurkin, K.A., Aksenov, E.M., *et al.*, New Stratigraphic Scale of the Precambrian in the Soviet Union, *Izv. Akad. Nauk, SSSR, Ser. Geol*, 1991, no. 4, pp. 3–16.

Semikhatov, M.A., Gorokhov, I.M., Kuznetsov, A.B., *et al.*, Strontium Isotope Composition in Sea Water at the Beginning of the Late Riphean: Limestones of the Lakhanda Group, the Uchur–Maya Region of Siberia, *Dokl. Akad. Nauk Ross. Akad. Nauk*, 1998, vol. 360, no. 2, pp. 236–240.

Sergeev, V.N., Microfossils from Cherts of the Middle Riphean Svetlinskii Formation of Uchur–Maya Region in Siberia and Their Biostratigraphic Significance, *Stratigr. Geol. Korrelyatsiya*, 2001 (in press).

Sergeev, V.N., Knoll, A.H., and Grotzinger, J.P., Paleobiology of the Mesoproterozoic Billyakh Group, Anabar Uplift, Northeastern Siberia, *J. Paleontol.*, 1995, vol. 69, no. 1.

Shalaginov, V.V. and Maslov, A.V., The Riphean of the Urals: Problems of Stratigraphy and Correlation, *Rifei Severnoi Evrazii. Geologiya. Obshchie problemy stratigrafii* (The Riphean of Northern Eurasia: Geology and General Problems of Stratigraphy), Yekaterinburg, 1997, pp. 78–85.

Shenfil', V.Yu., *Pozdnii dokembrii Sibirskoi platformy* (The Late Precambrian of the Siberian Platform), Novosibirsk: Nauka, 1991.

Stratigraficheskii slovar'. Verkhnii dokembrii (Severnaya Evraziya v granitsakh byvshego SSSR) (Stratigraphical Guide Book: The Upper Precambrian of Northern Eurasia within Limits of the Former Soviet Union), Moscow: Nauka, 1994.

Stratigrafiya SSSR. T. 2. Verkhnii dokembrii (Stratigraphy of the Soviet Union, vol. 2: The Upper Precambrian), Moscow: Nedra, 1963.

Stratotip rifeya. Paleontologiya. Paleomagnetizm (Stratotype of the Riphean: Paleontology and Paleomagnetism), Moscow: Nauka, 1982.

Stratotip rifeya. Stratigrafiya. Geokhronologiya (Stratotype of the Riphean: Stratigraphy and Geochronology), Moscow: Nauka, 1983.

Veis, A.F., Riphean and Vendian Microfossils from the Uchur–Maya and Turukhansk Regions of Siberia, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1988, no. 5, pp. 47–64.

Veis, A.F., Organic-Walled Microfossils of the Precambrian as Most Important Components of Ancient Biotas, *Problemy doantropogennoi evolyutsii biosfery* (Problems of Pre-Anthropogene Evolution of the Biosphere), Moscow: Nauka, 1993, pp. 265–282.

Veis, A.F., Microfossils in the Pre-Vendian Stratigraphy of the Proterozoic: Problems and Approaches, *Obshchie problemy stratigrafii i geologicheskoi istorii rifeya Severnoi Evrazii. Yekaterinburg* (General Problems of Stratigraphy and Geological History of the Riphean in Northern Eurasia), Yekaterinburg: Ural. Otd. Ross. Akad. Nauk, 1995, pp. 20–24.

Veis, A.F. and Petrov, P.Yu., The Main Peculiarities of the Environmental Distribution of Microfossils in the Riphean Basins of Siberia, *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 5, pp. 97–129.

Veis, A.F. and Vorob'eva, N.G., The Riphean and Vendian Microfossils from the Anabar Massif, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1992, no. 1, pp. 114–130.

Veis, A.F. and Vorob'eva, N.G., Microbiotas of the Kerpyl' Group in the Riphean Hypostratotype of Siberia, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 1, pp. 41–58.

Veis, A.F., Kozlova, E.V., and Vorob'eva, N.G., Organic-Walled Microfossils from the Riphean Type Section (Southern Urals), *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1990, no. 9, pp. 20–36.

Veis, A.F., Petrov, P.Yu., and Vorob'eva, N.G., Secular Transformations in the Facies–Ecological Structure of Ancient Biotas and the Riphean Stratigraphy, *Geol. Geofiz.*, 1998, vol. 39, no. 1, pp. 85–96.

Vinogradov, V.I., Upper Precambrian Deposits of the Siberian Platform: Epigenetic Transformations and Age Paradoxes, *Rossiiskii fond fundamental'nykh issledovanii v Sibirskom regione (zemnaya kora i mantiya)* (Russian Foundation for Basic Research in Siberian Regions: The Earth's Crust and Mantle), 1995, vol. 1, pp. 58–59.

Xiao, S., Knoll, A.H., and Kaufman, A.J., Neoproterozoic Fossils in Mezsoproterozoic Rocks? Chemostratigraphic Resolution of a Biostratigraphic Conundrum From the North China Platform, *Precambrian. Res.*, 1997, vol. 84, pp. 197–220.

Yankauskas, T.V., Late Precambrian and Cambrian Phytomicrofossils from the European Part of the Soviet Union and Their Stratigraphic Significance, *Abstract of Cand. Sci. (Geol.–Mineral.) Dissertation*, Moscow: Geol. Inst., Acad. Sci. USSR, 1982, p. 52.

Yankauskas, T.V., Mikhailova, N.S., German, T.N., *et al.*, *Mikrofossilii dokembriya SSSR* (Precambrian Microfossils in the Soviet Union), Leningrad: Nauka, 1989.

Zabrodin, V.E., The Riphean Microphytoliths of the Urals and Cis-Urals, *Abstract of Cand. Sci. (Geol.–Mineral.) Dissertation*, Moscow: Geol. Inst., Acad. Sci. USSR, 1967, p. 35.

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 447–460. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 29–42.
Original Russian Text Copyright © 2000 by Vilesov.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Fusulinid-Based Zonation of the Melekhov Horizon (Upper Carboniferous, Gzhelian Stage) in the Perm' Region

A. P. Vilesov

Perm' State University, ul. Bukireva 15, Perm', 614600 Russia

Received October 13, 1998; in final form, February 25, 1999

Abstract—Introduction of the Melekhov Horizon into the regional stratigraphic scale for the Upper Carboniferous of the Russian Platform is discussed. The new horizon corresponds to a separate regional sedimentation cycle that resulted in substantial reorganizations of benthic schwagerinid assemblages (Foraminifera, Schwagerinida) during the earliest and latest Melekhov epochs. It is suggested to include the Melekhov Horizon in regional stratigraphic schemes of the Urals. The subdivision of the new horizon in sections of the Perm' region into local *Occidentoschwagerina ancestralis* and *Occidentoschwagerina konovalovae* fusulinid zones is substantiated. Characteristics of the distinguished zones are presented, and their stratotype sections are described. The possibility of distinguishing these zones in sections of the southern Urals, southern Timan Ridge, Oka-Tsna Rampart, and Samarskaya Luka area is analyzed.

Key words: *Melekhov Horizon, Gzhelian, Carboniferous, fusulinids, zonal units, correlation, the Perm' region*

INTRODUCTION

On October 24, 1994, the Melekhov Horizon was considered and approved to be the unit of the regional stratigraphic scale for the Upper Paleozoic of the Russian Platform by the Bureau of the Russian Interdepartmental Stratigraphic Committee (RISC) for the central and southern Russian platform. The horizon corresponds in range to the *Daixina bosbytauensis–Daixina robusta* fusulinid zone (Makhlina and Isakova, 1997) also traceable confidently in the eastern sections of the Russian platform and in the Urals foredeep (*Pogranichnye otlozheniya...*, 1986; Konovalova, 1991; and others). The last circumstance allows us to use a new horizon in regional stratigraphic schemes of the Urals as well.

Makhlina and Isakova (1997), who introduced the new unit, explain the necessity of recognizing the *Daixina bosbytauensis–Daixina robusta* Zone and corresponding horizon as a consequence of their new position in the general stratigraphic scale. According to the resolution endorsed by the ISC Bureau on March 9, 1992, the boundary between the Carboniferous and Permian is placed at the base level of the fusulinid *Schwagerina vulgaris–Schwagerina fusiformis* Zone (*Postanovleniya MSK...*, 1992).[1] The underlying *Daixina bosbytauensis–Daixina robusta* Zone, the base of which was determined earlier as the lower boundary of the Asselian Stage and Permian System (*Postanovleniya MSK...*, 1985), was included thus into the Gzhelian Stage of the Upper Carboniferous that inevitably attributes the horizon rank to the zone.

In addition to formal reasons, there are other serious grounds for distinguishing the *Daixina bosbytauensis–Daixina robusta* Zone as a separate horizon:[2] the upper and lower boundaries of the zone are ecostratigraphic and mark certain events and corresponding substantial changes in the regional physicogeographical conditions responsible for taxonomic reorganizations in benthic assemblages of the past epicontinental sea.

The onset of transgression that replaced a considerable regression of the Late Carboniferous time was at the Melekhov time (Kalmykova, 1980; Kalmykova and Kashik, 1988; and others). The event is recorded in the holostratotype of the Melekhov Horizon, whose basal layer overlies an uneven surface of the variegated dolomitic marl bed (the so-called "Sinyukha") topmost in the Noginsk Horizon (Makhlina and Isakova, 1997). The transgression started in the Melekhov time and continued throughout the Asselian. The Asselian megacycle of transgressive sedimentation is subdivided in the Russian platform into two smaller mesocycles, the older one corresponding to the Melekhov and Kholodnyi Log horizons and the younger, spanning the range of the Shikhany Horizon. The former transgressive mesocycle of the second order comprises three first-

[1] In my opinion, the more plausible level for the Carboniferous–Permian boundary is the base of the *Daixina bosbytauensis–Daixina robusta* Zone (Vilesov, 1997b).

[2] Vilesov (1999) revised the generic affiliation of the *Daixina? robusta* Rauser group. Schwagerinids of the group were assumed to be primitive representatives of the *Globifusulina* genus. In this work, the generic affiliation of the *Daixina? robusta* Rauser and other "tumid Daixina forms" is given in accord with the changed nomenclature.

order cycles, one of which correlates with the Melekhov Horizon, whereas two others are equivalents of the Kholodnyi Log Horizon (Kalmykova and Kashik, 1974, 1988, and others).

General changes in the physicogeographical conditions at the beginning of the Melekhov time affected the biota of the East European paleogeographic province. The effect was especially dramatic for schwagerinids, the fast evolving and well studied group of fusulinids.

The appearance of several new genera in the order Schwagerinida was coeval to the onset of the Melekhov phase of the Asselian transgression. New genera quickly displaced genera dominant in assemblages of the Noginsk time of the Gzhelian Stage (Kalmykova, 1980; Rauser-Chernousova and Reitlinger, 1977; and others). Taxa that appear in the Melekhov time were genera *Occidentoschwagerina, Globifusulina, Praepseudofusulina*, and *Rugosochusenella*, subgenus *Bosbytauella* of the genus *Daixina*, and a peculiar group of *Triticites? fornicatus* Kanmera. The genus *Jigulites* and subgenus *Daixina*, both dominant among schwagerinids in the Noginsk time, died out. In the Melekhov schwagerinid assemblages, the "tumid Daixina" forms that represented primitive ancestors of the genus *Globifusulina*, become dominant, abundant and diverse in different facies environments. Schwagerinids of the Melekhov time populated a new habitat—the water layer above the bottom inhabited by algae and sedentary invertebrates. Thus the peculiar epibenthic group of schwagerinids appeared (the *Occidentoschwagerina* genus and some later genera with the "Schwagerina"-type spiral). Its emergence in the new habitat was favored by aromorphous transformation of skeletons. Genera from the Noginsk sediments (for instance, *Schellwienia, Rugosofusulina*) display the renewed species composition. The new genera migrated quickly from radiation centers to new epicontinental sea areas simultaneously with the gradual development of transgression. Their radiation was followed by active speciation. A glowing example is the genus *Praepseudofusulina* that originated in the Volga paleozoogeographic region (regional zoning after Kalmykova, 1980). Migrating eastward, northward, and northeastward, this genus gave rise to many new species inadequately studied so far.

The next transgressive sedimentation cycle of the first order also connected with reorganizations in schwagerinid assemblages is that of the latest Melekhov–earliest Kholodnyi Log time. The *Globifusulina* genus remained dominant at that time, but composition of prevailing species was renewed and primitive species of the genus were gradually replaced by higher forms. Representatives of the *Schwagerina* genus appear among epibenthic groups and quickly replaced *Occidentoschwagerina* forms. The schwagerinid assemblages of the Kholodnyi Log time differed from the Melekhov assemblages in that they were less endemic.

Thus, the necessity of distinguishing the Melekhov Horizon is evident from the history of schwagerinids, the most important Late Paleozoic orthostratigraphic group, which is reckoned to be the basic one when distinguishing and substantiating the Upper Carboniferous and Lower Permian horizons included in stratigraphic scales for the Russian platform and the Urals.

FUSULINID-BASED ZONATION OF THE MELEKHOV HORIZON

The comprehensive study on schwagerinid phylogeny and succession of their assemblages in the sections enables subdivision of the Melekhov Horizon into the local fusulinid zones. In particular, Davydov distinguished the *Daixina (Bosbytauella) postsokensis* and *Daixina (Bosbytauella) postgalloway* zones within this interval of sections studied in the southern Urals (Popov *et al.*, 1985; Davydov and Popov, 1986; and others). He also recognized the same zones in the Donetsk foredeep (Davydov, 1992). The possibility that analogs of the Melekhov Horizon can be subdivided on the basis of fusulinids was demonstrated for southern Timan Ridge as well (Konovalova, 1991).

My recent study of stratigraphic ranges of schwagerinids in the Gzhelian–Asselian boundary interval in the Perm' region allowed me to distinguish here the Melekhov Horizon with two local fusulinid zones of *Globifusulina robusta–Schellwienia porrecta* and *Praepseudofusulina netkatchensis* replacing one another upward in the section (Vilesov, 1997a, 1997b). Both local zones are reliably traced in a series of well-studied sections and correlated with local zonal units of the southern Urals. Their extension to the southern Timan Ridge seems to be possible.

This work presents substantiation and most complete characteristics of local fusulinid zones of the Melekhov Horizon in the Perm' region. Before proceeding further, we should consider first the most suitable candidates for the zonal index species.

In my previous publications (Vilesov, 1997a and 1997b), the chosen index species for local zones of the Melekhov Horizon in the Perm' region were not quite appropriate and did not meet current requirements for zonal biochronological scales (Chernykh, 1995). Since *Bosbytauella* species, e.g., *Daixina (Bosbytauella)* forms, whose phylogeny was used by Davydov as a basis for fusulinid zonation in the southern Urals, is missing from the regional sections, they cannot be taken for index species of local zones. At the first glance, the *Globifusulina* genus dominant in schwagerinid assemblages of the Melekhov time appears to be suitable for selection of zonal index species. However, the phylogeny of globifusulins is poorly understood at present thus being inappropriate for biozonation. The complimentary study of the genus taxonomic diversity and revision of stratigraphic ranges of its species

should be done, because published data are controversial and require verification.

The study on phylogenetic lines of several fast-evolving schwagerinid genera established that representatives of the genus *Occidentoschwagerina* can be used as zonal index species of the Melekhov Horizon. Their evolution was analyzed in detail in a special work (Vilesov, 1998), where general phylogenetic tendencies of this peculiar schwagerinid group were outlined.

In the Melekhov time, this group evolved displaying the following characteristic features: the growing isolation of juvenarium, the height increase in mature convolutions, the diminishing folding of septa, and the general growth of shells in size. All that resulted in appearance of tumid occidentoschwagerins, for instance, of *Occidentoschwagerina konovalovae* Vilesov and *O. sartauensis* (Davidov), in the later half of the Melekhov time that was followed later, in the earliest Asselian, by origin of first schwagerins still possessing many features of the ancestor genus (*Schwagerina fusiformis* Krot., *S. poljarica* Grozd., and others).

The phylogenetic line of *Occidentoschwagerina ancestralis* Echlakov, 1977, *Occidentoschwagerina konovalovae* Vilesov, 1998 and, finally, *Schwagerina fusiformis* Krotow, 1888, where the aforementioned evolutionary trends are well pronounced, can be used as a basis for the biozonation. Taking occidentoschwagerins for index species of zonal units of the Melekhov Horizon, we obtain in addition the phylogenetic substantiation of the Carboniferous–Permian boundary, because schwagerins (*Schwagerina* Moeller, sensu Rauser) representing index species of the Asselian zonation are, in my opinion, direct descendants of the former (Vilesov, 1998):[3]

STRATOTYPES OF LOCAL ZONAL UNITS OF THE MELEKHOV HORIZON

Before substantiation of local zones of the Melekhov Horizon, it is necessary to present first the description and paleontological characteristics of their stratotypes.

The Ostanets section (Beds 2–4) is selected as stratotype of the *Occidentoschwagerina ancestralis* Zone, and the Kholodnyi Log section (Exposure 24, beds 2–4) is that of the *Occidentoschwagerina konovalovae* Zone. Both sections are located at the Kos'va River, 1.5 km upstream of the settlement of Verkhnyaya Gubakha (Mt. Gubakha, Perm' region, Russia; see Fig. 1).

Kholodnyi Log Section

The Kholodnyi Log section corresponding to stratotype of the Kholodnyi Log Horizon of the Asselian Stage is simultaneously the parastratotype of some fusulinid zones. The section is exposed in cliffs up to 120 m high along the right bank of the Kos'va River and on both sides of the Kholodnyi Log (a ravine). In this site, the succession of Upper Carboniferous and Lower Permian limestone beds yields abundant and diverse marine fossils. The comprehensive description of the Carboniferous rocks was published by Shcherbakova *et al.* (1972), whereas the detailed description of Permian strata is given by Ekhlakov and Zolotova (1986), whose data are reproduced in a later publication (*Permian System...*, 1993). As the result of recent studies, characteristics of fusulinid assemblages from Permian deposits were verified and better understood. Presented below is the new description of Exposure 24 at the Kholodnyi Log site (Fig. 2), where almost the whole Upper Carboniferous Melekhov Horizon and the basal part of the Lower Permian Kholodnyi Log Horizon are exposed (the exposure number is after Zolotova and Ekhlakov).

Upper Carboniferous

Gzhelian Stage

Melekhov Horizon

Daixina bosbytauensis–Globifusulina robusta Zone

Local *Occidentoschwagerina ancestralis* Zone

Bed 1: light gray to yellowish algal–detrital, locally bryozoan- or crinoidal–detrital limestone; the rock is extremely tough, massive to bedded, fine-grained, and bituminous in the upper half of the bed. Organic remains: calcareous algae, smaller foraminifers, fenestrate and ramified bryozoans, solitary corals, crinoids, and brachiopods. Identified species of rare schwagerinids are *Globifusulina vozhgalensis biconica* (Poloz.), *G. tumifacta* (Echlak. et Scherbak.), *G. robusta* (Raus.), *G. pechorica* (Vol.), *Occidentoschwagerina ancestralis* Echlak., *O. acerba* Vilesov. The bed thickness is 4.90 m.

Local *Occidentoschwagerina konovalovae* Zone

Bed 2: Yellowish-gray to light gray algal–palaeoaplisid limestone; the rock is fissured, fine-grained, massive to bedded, bearing calcareous algae *Globuliferoporella symetrica* (Johnson), *Pseudoepimastopora* sp., and *Giroporella dissecta* Tchuv. in association with smaller foraminifers (*Tetrataxis* sp., *Ammovertella* sp., *Climacammina* sp., *Globivalvulina* sp.), crinoids, brachiopods, gastropods, and ramified bryozoans. Schwagerinids are abundant in the upper part of the bed that yields *Globifusulina* aff. *pomposa* (Sjom.), *G*: cf. *tumifacta* (Echlak. et Scherbak.), *G. versabile* (Bensh), *Rugosochusenella simplex* (Mikh.), *Triticites? fornicatus* (Kanmera), *T.? subschwagerinoides* f. *grandis* (Grozd.), *T.*? aff. *uniensis* (Grozd. et Leb.), *T. kreekensis* Thompson, *Occidentoschwagerina* cf. *simplex* (Vol.), *O. konovalovae* Vilesov, and *Praepseudofusulina propria* (I. Tchern.). The bed thickness is 2.50 m.

[3] It should be noted that I follow in this work the systematics elaborated by Rauser-Chernousova with co-authors (1996) for the subfamily Schwagerininae Dunbar et Henbest and order Schwagerinida.

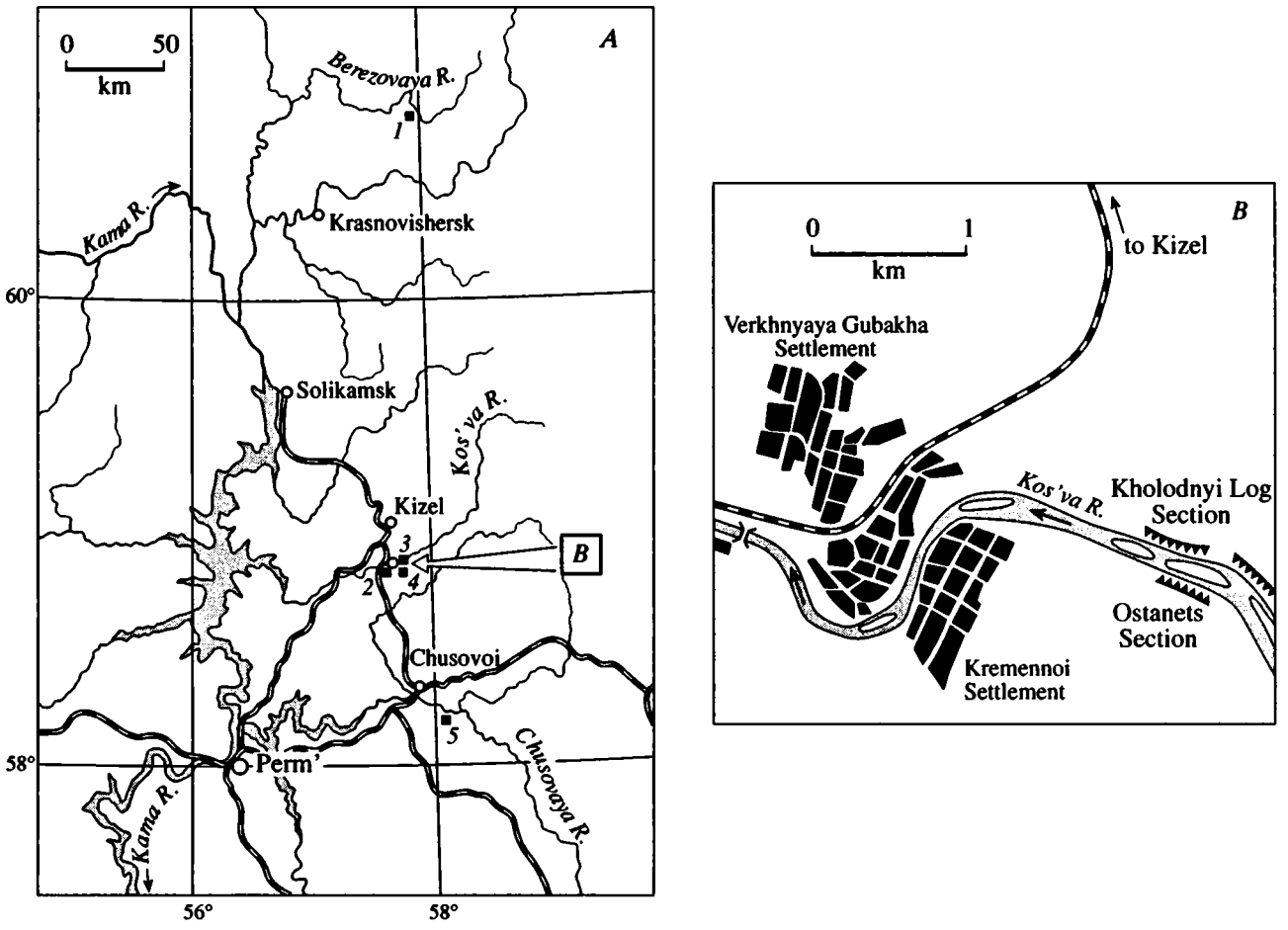


Fig. 1. Exposures of the Melekhov Horizon in the Perm' region (*A*) and stratotype section localities (*B*): (*1*) Kamen' Stolby; (*2*) Most and Nizhnyaya Gubakha; (*3*) Kholodnyi Log; (*4*) Ostanets; (*5*) Plakun.

Bed 3: gray to light gray palaeoaplisid–algal, algal–palaeoaplisid, locally foraminiferal–algal limestones with abundant and diverse detritus; the rocks are massive to bedded, porous, fine- to medium-grained, slightly bituminous in the upper part of the bed. Groups of organic remains: calcareous algae *Globuliferoporella* sp., *Pseudoepimastopora* sp., *Epimastopora grandis* Tchuv. et Anf., *Giroporella* sp., and *Tubiphytes* sp.; smaller foraminifers *Amovertella* sp., *Eotuberitina* sp., *Bradyina* sp., *Climacammina* sp., *Tetrataxis* sp., *Dekerella* sp., *Rectocornuspira* sp., *Tikhinella* sp., *Mesolasiodiscus* sp., and others; solitary Rugosa; brachiopods; crinoids; ramified and fenestrate bryozoans. Identified schwagerinid species are *Globifusulina vozhgalensis* (Raus.), *G. tumifacta* (Echlak. et Scherbak.), *G. versabile* (Bensh), *G. berestyankica* (Vilesov), *Rugosochusenella simplex* (Mikh.), *R. paragregaria* (Raus.), *Triticites? fornicatus* (Kanmera), *T.? subschwagerinoides* f. *grandis* (Grozd.), *T.*? aff. *uniensis* (Grozd. et Leb.), *Occidentoschwagerina* aff. *simplex* (Vol.), *O. kosvaensis* Echlak., *O. konovalovae* Vilesov, *O. ancestralis* Echlak., *O. echlakovi* Vilesov, *Rugosofusulina* cf. *aktjubensis* Raus., *R. subundulata* Sjom., *Praepseudofusulina impercepta* (Jagof.), *P. netkatchensis* (Ketat), *P. fastuosa* (Ketat), *Andersonites triangulatus* (Zol.), *Pseudofusulina*? aff. *diserta* Scherb., and others. The bed thickness is 7.00 m.

Bed 4: dark gray algal–detrital fine-grained clayey limestone; the rock is indistinctly bedded, bituminous in the lower part, silicified and dolomitic in the upper part. Organic remains: calcareous algae, smaller foraminifers of genera *Bradyina* and *Ammodiscoides*, rare schwagerinids (identified species is *Anderssonites ognevae* Vilesov), large solitary Rugosa, tabulates, and brachiopods. The bed thickness is 1.20 m.

Lower Permian

Asselian Stage

Kholodnyi Log Horizon

Schwagerina vulgaris–Sch. fusiformis Zone

Bed 5: gray to light gray organogenic–detrital limestones; the rocks are fine- to medium-grained, massive or bedded, and highly recrystallized. An interlayer of brownish gray fusulinid–crinoidal limestone 0.20 m thick occurs at the bed base. Organic remains: calcareous algae, palaeoaplisinds, smaller foraminifers,

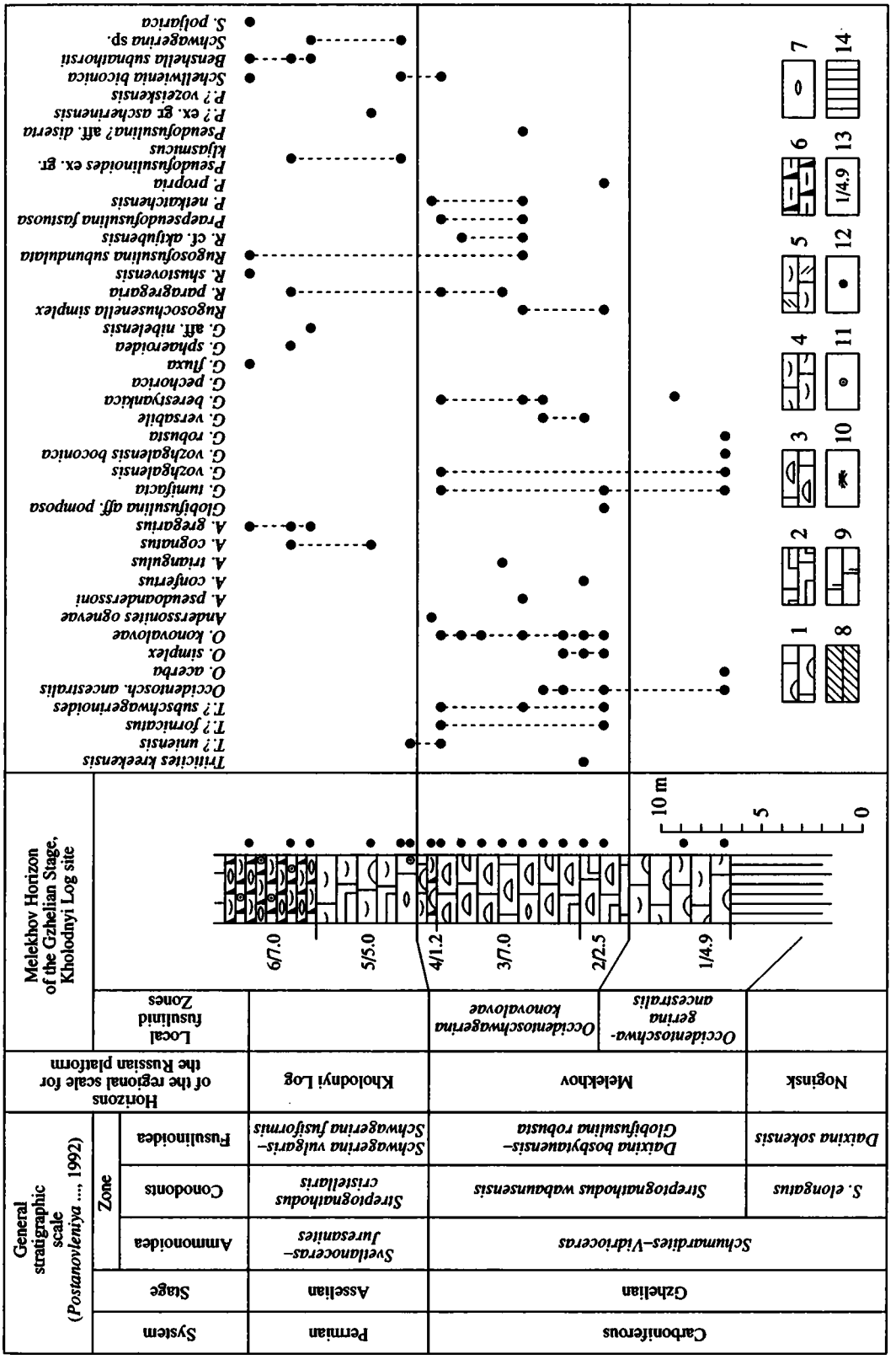


Fig. 2. Stratotype of the local *Occidentoschwagerina konovalovae* Zone of the Melekhov Horizon, Perm' region, Kholodnyi Log site. (1–7) limestone types: (1) massive- to thick-bedded algal, (2) massive- to thick-bedded palaeoaplisinid, (3) palaeoaplisinid–algal, (4) detrital, (5) slimy–detrital, (6) medium- to thin-bedded bituminous and clayey, (7) fusulinid; (8) medium- to thin-bedded dolomite; (9) dolomitized limestone; (10) bryozoans; (11) crinoids; (12) sampling levels of fusulinids; (13) bed number and thickness, m; (14) unexposed intervals and talus.

crinoids, brachiopods, tabulates. Schwagerinids are recrystallized and deformed; species identified among them are *Schwagerina* sp., *Anderssonites cognatus* (Echlak.), *Schellwienia biconica* (Scherb.), *Pseudofusulinoides* ex gr. *kljasmicus* (Sjom), *Pseudofusulina*? ex gr. *ascherinensis* Sjom. The bed thickness is 5.0 m.

Bed 6: dark gray to black, organogenic–polydetrital (mainly fusulinid– and crinoidal–detrital) limestone with numerous Syringopora colonies; the rock is microlaminated, fine-grained, and highly bituminous. Organic remains: calcareous algae (*Tubiphytes* forms), smaller foraminifers (*Deckerella* sp., *Eotuberitina* sp., *Climacammina* sp., *Palaeotextularia* sp., *Globivalvulina* sp., *Ammodiscus* sp., and others), crinoids (commonly articulate fragments of the columns), brachiopods, and ramified bryozoans. Schwagerinids are abundant, represented by species *Schwagerina* sp., *S. poljarica* (Grozd.), *Schellwienia uberata* (Kon.), *Rugosofusulina* cf. *burkemensis* Vol., *R. subundulata* Sjom., *Rugosochusenella shustovensis* (Scherb.), *R. paragregaria* (Raus.), *Pseudofusulinoides* ex gr. *kljasmicus* (Sjom.), *Pseudofusulina*? ex gr. *ascherinensis* Sjom., *P.*? aff. *netchaevi* Dav., *P.? signata* Kon., *P.? vosejskensis* Kon., *Benshella subnathorsti* (Lee), *Anderssonites cognatus* (Echlak.), *A. gregarius* (Lee), *A*: ex gr. *gregarius* (Lee), *A. cognatus* (Echlak.), *Globifusulina fluxa* (Grozd.), *G. sphaeroidea* (Raus.), *G*: aff. *nibelensis* (Vol.), and others. The bed thickness is 7.0 m.

Ostanets Section

The Ostanets section is studied in small rocky scarps and separate bedrock exposures on the left river bank opposite the Kholodnyi Log section. The uppermost Gzhelian (Upper Carboniferous) and lowermost Asselian (Lower Permian) limestone with various fossils are main rocks of the section originally described by Shcherbakova (1986). My own observations allowed me to draw biostratigraphic boundaries differently (Fig. 3). The bed succession in the Ostanets section is as follows (bed numbers after Shcherbakova).

Upper Carboniferous

Gzhelian Stage

Noginsk Horizon

Daixina sokensis Zone

Bed 1: brownish gray to dark gray fusulinid–algal limestone; the rock is fine-grained, compact, massive to bedded and microlaminated in some interlayers (interlayers show numerous stylolite sutures and fusulinid compressions). Organic remains: palaeoaplisinids, calcareous algae, and smaller foraminifers (*Tuberitina* sp., *Brunsia* sp., *Eotubertina* sp., *Globivalvulina* sp., *Tikhinella* sp., *Climacammina* sp.). Determined fusulinid species are *Quasifusulina longissima* Moell., *Ruzhenzevites* sp., *Daixina* aff. *transitoria* Alks. et Poloz., *D. licharevi* Dav., *Jigulites* cf. *magnus* Ros., and *Triticites rossicus* Bensh. In the stripped exposure bedrocks, the bed is 1.0 m thick. The unexposed part of the section is 2.0 m thick.

Melekhovo Horizon

Daixina bosbytauensis–Globifusulina robusta Zone

Local *Occidentoschwagerina ancestralis* Zone

Bed 2: brownish gray dolomites, fine-grained with small bituminous inclusions and interbeds of light gray algal–detrital fine-grained dolomitized limestone. Organic remains: calcareous algae, smaller foraminifers, and rare fusulinids. Schwagerinids are represented by *Anderssonites paraanderssoni* (Raus.) and *Occidentoschwagerina ancestralis* Echlak. The bed thickness is 1.00 m. The unexposed part of the section is 2.50 m thick.

Bed 3: brownish gray fine-grained palaeoaplisinid–detrital limestone with microcloddy matrix; the rock is thick-bedded, hard, and dolomitic. Organic remains: calcareous algae (*Tubiphytes* sp., *Pseudoepimastopora* sp., *Globuliferoporella* sp.), smaller foraminifers (*Tuberitina* sp., *Eotuberitina* sp., *Climacammina* sp., *Nodosaria* sp., *Bradyina* sp.), palaeoaplisinids, solitary corals, brachiopods, ostracods, and bryozoans. Schwagerinids are represented by the following species: *Occidentoschwagerina acerba* Vilesov, *O. ancestralis* Echlak., *O.* aff. *ancestralis* Echlak., *O.* aff. *simplex* (Vol.), *Globifusulina* aff. *pomposa* (Sjom.), *G. tumifacta* (Echlak. et Scherbak.), *Anderssonites anderssoni* (Schellw.), *A. ognevae* Vilesov, *A. paraanderssoni* (Raus.), *A. subovatus* Kon.), *Schellwienia porrecta* (Sjom.), and *Sch.*? aff. *antropovi* (Malk.). The bed is seen in small bedrock outcrops on slopes of the first and second terraces above the floodplain. The bed thickness is 1.50 m.

Bed 4: light gray to gray palaeoaplisinid limestone with grumous matrix; the rock is fine-grained, thick-bedded, and irregularly dolomitized. Organic remains: smaller foraminifers, corals, crinoid columnals, palaeoaplisinids, brachiopods, and bryozoans. Identified schwagerinid species are *Anderssonites gerasimovi* (Vilesov), *A. confertus* (Vilesov), *A. paraanderssoni* (Raus.), *Occidentoschwagerina ancestralis* Echlak., and *Schellwienia*? aff. *antropovi* (Malk.). The bed was observed in two outcrops of bedrocks on the slope of the second terrace above the floodplain and near the river-water level. The outcrops are separated by an unexposed interval 2.0 m thick. The bed thickness is 8.0 m. The total thickness of the local zone is 13 m.

Local *Occidentoschwagerina konovalovae* Zone

Beginning from Bed 5, rocks are exposed near the river-water level in a blind bedrock wall up to 4.0 m high.

Bed 5: brownish gray to dark gray palaeoaplisinid and palaeoaplisinid–detrital limestones with grumous slimy cement; the rocks are fine- and medium-grained, thick-bedded, bearing individual large schwagerinids. Organic remains: calcareous algae (*Tubiphytes* sp.), smaller foraminifers (*Tuberitina* sp., *Eotuberitina* sp., *Globivalvulina* sp., *Climacammina* sp., *Brunsia* sp.,

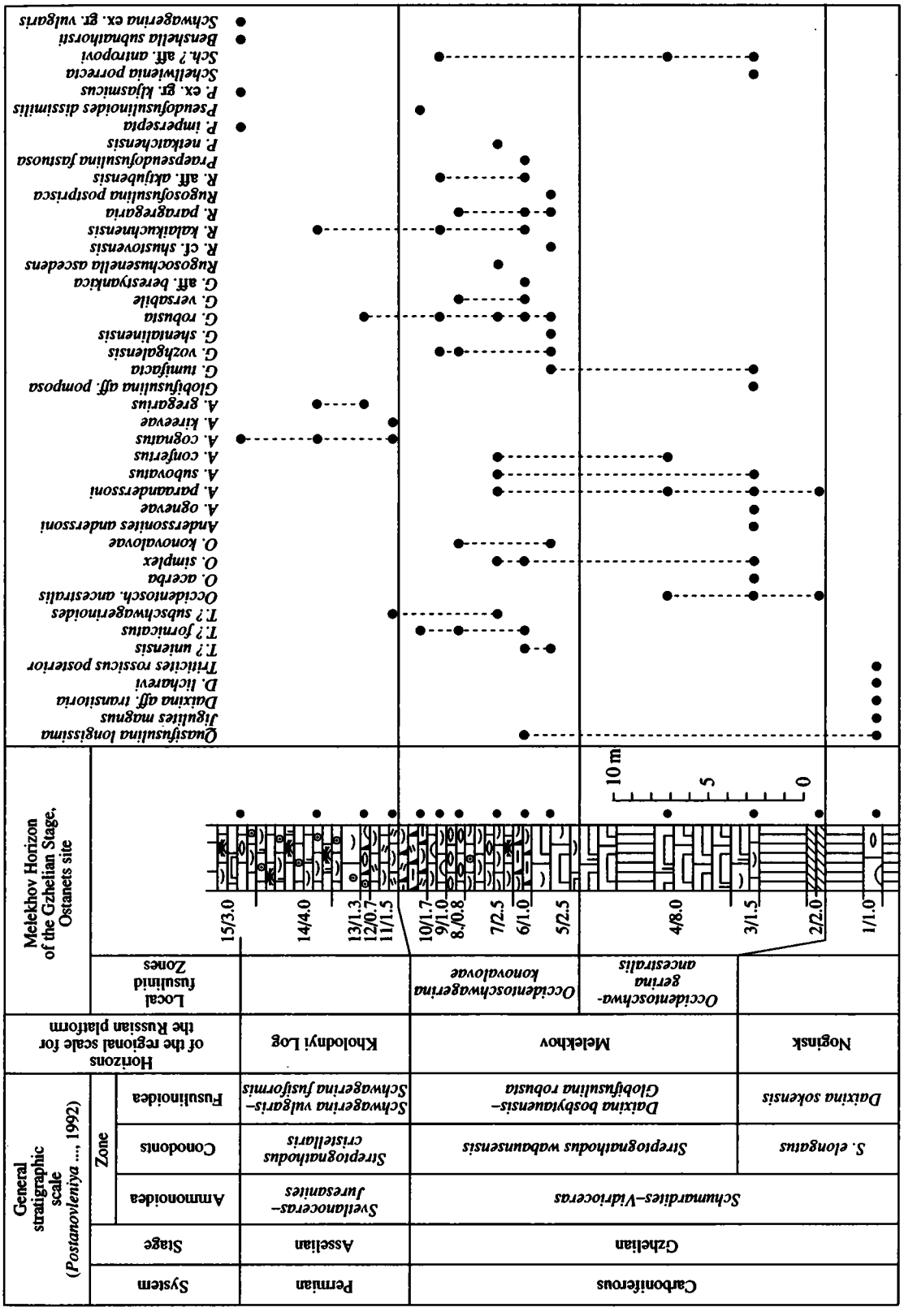


Fig. 3. Stratotype of the local *Occidentoschwagerina ancestralis* Zone of the Melekhov Horizon, Perm' region, Ostanets site (symbols as in Fig. 2).

Tetrataxis sp., *Monotaxinoides* sp.), palaeoaplisinids, brachiopods, corals, and bryozoans. Determined schwagerinid species are *Globifusulina vozhgalensis* (Raus.), *G. shentalenensis* (Jagof.), *G. robusta* (Raus.), *G.* cf. *robusta* (Raus.), *G. tumifacta* (Echl. et Scherb.), *Rugosochusenella* cf. *shustovensis* (Scherb.), *R. paragregaria* (Raus.), *Rugosofusulina postprisca* Bensh, and *Triticites? uniensis* Grozd. et Leb. The bed thickness is 2.5 m.

Bed 6: brownish gray to black organogenic–detrital limestone; the rock is fine- to medium-grained, thin-bedded to foliated, bituminous, and clayey. Organic remains: calcareous algae (*Tubiphytes* sp.), smaller foraminifers (*Bradyina* sp., *Tuberitina* sp., *Nankinella* sp., *Pseudoendothira* sp.), corals, and crinoids. Identified fusulinid species are *Quasifusulina longissima* (Moell.), *Globifusulina robusta* (Raus.), *G*: aff. *berestyankica* (Vilesov), *Praepseudofusulina fastuosa* (Ketat), *Occidentoschwagerina simplex* (Vol.), *O*: cf. *konovalovae* Vilesov, *Rugosochusenella kalaikuchnensis* Dav., *R. paragregaria* (Raus.), *Triticites? fornicatus* Kanmera, *T.*? cf. *uniensis* Grozd. et Leb. The bed thickness is 1.0 m.

Bed 7: light gray organogenic–detrital limestone with fine-grained matrix; the rock is fine- to medium-grained, medium-bedded, and fissured. Organic remains: calcareous algae, smaller foraminifers (*Nankinella* sp., *Tetrataxis* sp., and others), bryozoans, and crinoids. Identified schwagerinid species are *Anderssonites subovatus* (Kon.), *A. confertus* (Vilesov), *Globifusulina robusta* (Raus.), *Triticites? subschwagerinoides* f. *grandis* Grozd., *Rugosofusulina* cf. *aktjubensis* Raus., *Rugosochusenella ascedens* (Raus.), *Occidentoschwagerina simplex* (Vol.), and *Praepseudofusulina netkatchensis* (Ketat). The bed thickness is 2.5 m.

Bed 8: brownish gray fusulinid limestone; the rock is medium-bedded, with even bedding planes. Organic remains: fusulinids, crinoid columnals, and solitary corals. Limestone yielded schwagerinids *Globifusulina vozhgalensis* (Raus.), *G.* cf. *versabile* (Bensh), *Triticites? fornikatus* (Kanmera), *Occidentoschwagerina konovalovae* Vilesov, and *Rugosochusenella paragregaria* (Raus.). The bed thickness is 0.8 m.

Bed 9: dark brownish gray organogenic–detrital (algal– and foraminiferal–detrital) limestones with grumous cement; the rocks are fine- to medium-grained, medium-bedded, rudaceous in the upper part. Organic remains: calcareous algae (*Epimastopora* sp.), smaller foraminifers (*Glomospira* sp., *Palaeotextularia* sp.), crinoid columnals, and brachiopods. Identified schwagerinid species are *Globifusulina robusta* (Raus.), *G. vozhgalensis* (Raus.), *Occidentoschwagerina* sp., *Rugosofusulina* ex gr. *aktjubensis* Raus., and *Schellwienia?* aff. *antropovi* (Malk.). The bed thickness is 1.0 m.

Bed 10: limestone dark brownish gray to black in color; the rock is fine- to medium-grained, micro- and thin-bedded, slimy–detrital, clayey, and bituminous. The basal part is algal–detrital and foliated, with compressed fusulinids on bedding planes; in the central part, limestone is highly bituminous, foliated, with microstylolites; in the top interval, the rock is slimy-detrital and compact, with irregular bituminous impregnations. Organic remains: calcareous algae, smaller foraminifers, poorly preserved fusulinids, palaeoaplisinids, bryozoans, crinoid stems, and brachiopods. Identified schwagerinid species are *Pseudofusulinoides dissimilis* (Scherb.) and *Triticites? fornikatus* Kanmera. The bed thickness is 1.7 m. The total thickness of the local zone is 9.5 m.

Lower Permian

Asselian State

Kholodnyi Log Section

Schwagerina vulgaris–Sch. fusiformis Zone

Bed 11: gray slimy–detrital limestone; the rock is medium-grained, thin- to medium-bedded, compact, clayey, and bituminous. Organic remains: calcareous algae (*Tubiphytes* sp.), smaller foraminifers (*Tuberitina* sp., *Climacammina* sp., *Bradyina* sp.), crinoid columnals, and brachiopods. Identified schwagerinid species are *Anderssonites cognatus* (Echlak.), *A. kireevae* (Scherb.), and *Triticites? subschwagerinoides* Grozd. The bed thickness is 1.5 m.

Bed 12: dark gray, slightly brownish limestones; the rocks are organogenic–detrital (remains of fusulinids, crinoids, and algae dominate in detritus) or algal–detrital, coarse-grained, foliated, and bituminous. In the basal part, limestone shows light spots consisting of coarse-grained crystalline calcite. Organic remains: calcareous algae, smaller foraminifers (*Brunsia* sp., *Nodosaria* sp.), bryozoans, crinoid columnals, brachiopods, palaeoaplisinids, and solitary corals. Identified schwagerinid species are: *Globifusulina* aff. *robusta* (Raus.) and *Anderssonites gregarius* (Lee). The bed thickness is 0.7 m.

Bed 13: light gray, crinoidal–detrital, medium- to coarse-grained, massive limestone clayey in the upper part. Organic remains: crinoids, bryozoans, smaller foraminifers, solitary corals, and calcareous algae. The bed thickness is 1.3 m.

Bed 14: gray to dark gray, bryozoan–crinoidal–detrital limestone; the rock is fine- to medium-grained, foliated, and partly dolomitized. Organic remains: smaller foraminifers, fusulinids (*Anderssonites cognatus* (Echlak.), *A. gregarius* (Lee), *Rugosochusenella kalaikuchnensis* (Dav.), brachiopods, corals, crinoids, and bryozoans. The bed thickness is 4.0 m.

Bed 15: light gray, organogenic–detrital limestone with grumous cement; the rock is fine- to medium-grained, medium-bedded, and dolomitic. Highly recrystallized schwagerinids are common near the bed top. Organic remains: calcareous algae (*Tubiphytes* sp.), smaller foraminifers (*Tuberitina* sp., *Palaeotextularia* sp.), bryozoans, crinoid columnals, palaeoaplisinids, and brachiopods. Identified schwagerinid species are *Benshella subnathorsti* (Lee), *Andersso-*

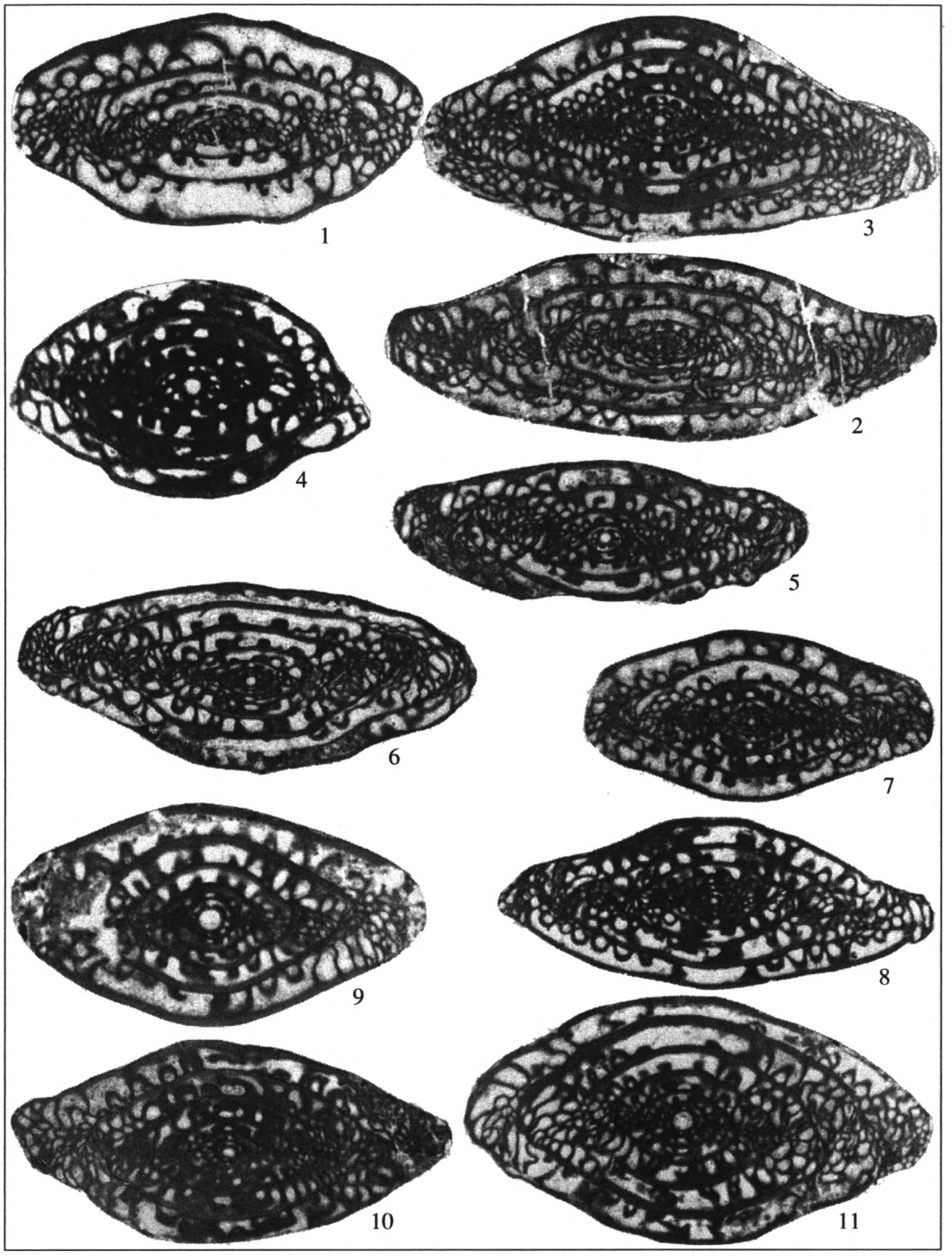


Plate I. Schwagerinids from the *Occidentoschwagerina ancestralis* Zone of the Melekhov Horizon, the Perm' region (magnification 15 for all specimens, except for figs. 2, 4, and 11): (1) *Occidentoschwagerina ancestralis* Echlakov, specimen 3-4/2, axial section, the Ostanets site, Bed 3; (2) *Occidentoschwagerina acerba* Vilesov, holotype, specimen 3-1/1, axial section, ×12.5, ditto, Bed 3; (3) *Anderssonites ognevae* Vilesov, specimen 3-4/1, axial section, ditto, Bed 3; (4) *Triticites? nadezhdae* (Grozdilova), specimen Z-2-19, axial section, ×20, the Nizhnyaya Gubakha site, Bed 7; (5) *Schellwienia emaciata* (Konovalova), specimen Zh-3-2, axial section, ditto, Bed 7; (6) *Schellwienia visotchnajaensis* (Konovalova), specimen 3303, axial section, ditto, Bed 7; (7) *Schellwienia porrecta* (Sjomina), specimen Z-2-16, axial section, ditto, Bed 7; (8) *Schellwienia acuminulata* (Echlakov), specimen Z-2-32, axial section, ditto, Bed 7; (9) *Globifusulina* cf. *vozhgalensis* (Rauser), specimen 3-1/3, axial section, the Ostanets site, Bed 3; (10) *Globifusulina pechorica* (Volozhanina), specimen K-1-1, axial section, the Nizhnyaya Gubakha site, Bed 9 (foot); (11) *Globifusulina tumifacta* (Echlakov et Scherbakova), specimen 3-1/6, oblique section, (×12.5), the Ostanets section, Bed 3.

nites cognatus (Echlak.), *Pseudofusulinoides* ex gr. *kljasmicus* (Sjom.), *Praepseudofusulina impersepta* (Jagof.), and *Schwagerina* ex gr. *vulgaris*: The bed thickness is 3.0 m.

In the Ostanets Section, the boundary between systems is drawn slightly below the first appearance level of *Schwagerina* representatives. In this case, the boundary position is established on the basis of following changes in schwagerinid assemblages: the appearance of characteristic *Anderssonites* forms, for instance, of *Anderssonites cognatus* (Echlak.); the complete disappearance of *Occidentoschwagerina* species and globifusulinids of the group *Globifusulina robusta* (Raus.). In other sections along the Kos'va River (Kholodnyi Log, Nizhnyaya Gubakha), the appearance of schwagerinids is concurrent with the mentioned changes in assemblages.

In the Ostanets section, Shcherbakova (1986) separated the *Daixina bosbytauensis–Globifusulina robusta* and *Schwagerina vulgaris–Sch. fusiformis* zones at the base of Bed 8 (the level is now accepted for the Carboniferous–Permian boundary). In my opinion, the boundary level is poorly substantiated and must be placed somewhat lower. The schwagerinid assemblage from beds 8–10 is typical of the Melekhov Horizon, since dominant in the assemblage are globifusulinids of the group *Globifusulina robusta* (Raus.) and *Occidentoschwagerina* forms; the only schwagerinid species from Bed 8 was identified by Shcherbakova as doubtful.

The lithological and paleontological characteristics of the Melekhov Horizon in the Perm' region were described by Shcherbakova and Shcherbakov (1994) for the Plakun section at the Chusovaya River, by Vilesov (1997c) for the Nizhnyaya Gubakha section at the Kos'va River, by Zolotova and Provorov (1974) for the Most Section at the same river, and by Ekhlakov and Zolotova (1986) for the Kamen' Stolby section at the Berezovaya River.

SUBSTANTIATION AND CHARACTERISTICS OF LOCAL FUSULINID ZONES OF THE MELEKHOV HORIZON

The *Occidentoschwagerina ancestralis* Zone is basal in the Melekhov Horizon. It is distinguished in sections Kholodnyi Log, Ostanets, Nizhnyaya Gubakha, Most (the Kos'va River), Plakun (the Chusovaya River), Kamen' Stolby (the Berezovaya River); all the localities are shown in Fig. 1. The lower boundary of the zone coincides with the base of the *Daixina bosbytauensis–Globifusulina robusta* Zone and is drawn at the appearance level of species *Occidentoschwagerina ancestralis* Echlak (Plate I). The appearance of other primitive *Occidentoschwagerina* forms and first *Globifusulina* species (the group *Globifusulina robusta* Raus.) is confined to the zone base as well. The following representatives of the mentioned genera are most characteristic of the zone: *Occidentoschwagerina simplex* (Vol.), *O. acerba* Vilesov, *Globifusulina robusta* (Raus.), *G. vozhgalensis* (Raus.), *G. tumifacta* (Echl. et Scherbak.), *G. pechorica* (Vol.), *G. subrobusta* (Dav.), and *G. pomposa* (Sjom.).

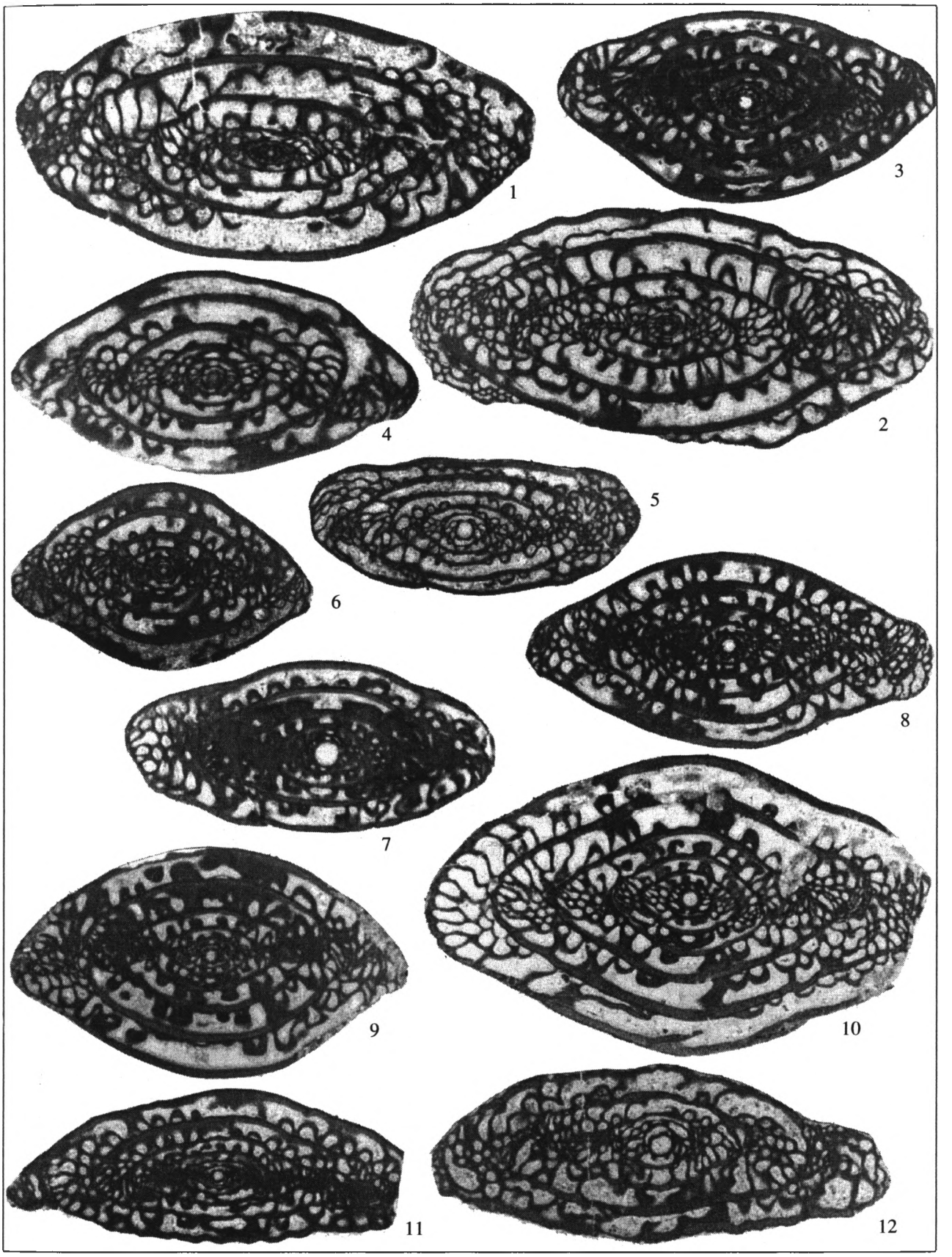
Single representatives of the *Praepseudofusulina* genus, e.g., *P. cara minima* (Isak.), also appear for the first time in the *ancestralis* Zone.

In the *ancestralis* Zone, the *Schellwienia* group substantially changes its species composition as compared to that characterizing the underlying *Daixina sokensis* Zone, and new *Schellwienia* species become sometimes dominant in the fusulinid assemblage, for instance, in the Nizhnyaya Gubakha section (Vilesov, 1997c). The most characteristic of the group are *Schellwienia porrecta* (Sjom.), *S. voseiensis* (Kon.), *S. emaciata* (Kon.), *S. visotchnajaensis* (Kon.), and *S. acuminulata* (Echlak.). In addition, the schwagerinid assemblage of the zone includes *Anderssonites* species, namely *A. ognevae* Vilesov, *A. paraanderssoni* (Raus.), *A. subovatus* (Kon.), and *A. confertus* (Vilesov), all associated with representatives of the group *Triticites? nadaezhdae* (Grozd.) peculiar in morphology.

The *Occidentoschwagerina ancestralis* Zone varies in thickness from 4 m in the Plakun section (normal bedded limestones) to 13 m in the Ostanets Section (bedded and biohermal limestones).

The *Occidentoschwagerina konovalovae* Zone is distinguished in the Kholodnyi Log, Ostanets, Nizhnyaya Gubakha, Most, and Kamen' Stolby sections. The lower boundary of the zone corresponds to the first appearance level of *Occidentoschwagerina konovalovae* Vilesov (Plate II). Some other species of the *Occidentoschwagerina* genus appear here as well, for instance, *O. kosvaensis* Echlak. and *O. echlakovi*

Plate II. Schwagerinids from the *Occidentoschwagerina konovalovae* Zone of the Melekhov Horizon, the Perm' region (magnification 15, except for Fig. 4): (1) *Occidentoschwagerina konovalovae* Vilesov, holotype, specimen 24-2-3/3, axial section, the Kholodnyi Log site, Exposure 24, Bed 2; (2) *Occidentoschwagerina echlakovi* Vilesov, holotype, specimen 24-2-2/5, axial section, ditto, Exposure 24, Bed 2; (3) *Globifusulina ponderosa* (Alksne), specimen N-3-3, axial section, the Nizhnyaya Gubakha Section, Bed 9; (4) *Praepseudofusulina netkatchensis* f. *ventricosa* (Ketat), specimen F-1-5, axial section, ×20, ditto, Bed 9; (5) *Praepseudofusulina netkatchensis* f. *ovata* (Ketat), specimen 4493, axial section, the Kamen' Stolby site, Exposure 21, Bed 12; (6) *Likharevites subschwagerinoides forma grandis* (Grozdilova), specimen 24-2-2/6, axial section, the Kholodnyi Log site, Exposure 24, Bed 2; (7) *Praepseudofusulina* aff. *busulukensis* (Dobrokhotova), specimen 3298, axial section, the Nizhnyaya Gubakha site, Bed 9; (8) *Globifusulina vozhgalensis* (Rauser), specimen U-3-3, axial section, ditto, Bed 9; (9) *Globifusulina* cf. *robusta* (Rauser), specimen T-1-2, axial section, ditto, Bed 2; (10) *Globifusulina versabile* (Bensh), specimen F-2-2, slightly biased section, the Nizhnyaya Gubakha Section, Bed 9 (middle part); (11) *Rugosochusenella simplex* (Z. Mikhailova), specimen 24-3-3/17, axial section, the Kholodnyi Log Section, Exposure 24, Bed 3; (12) *Rugosofusulina aktjubensis* Rauser, specimen 24-3-8/3, oblique section, the Kholodnyi Log site, Exposure 24, Bed 3.


1
3
2
4
5
6
8
7
10
9
11
12

Vilesov. Moreover, the level also marks the first appearance of *Rugosochusenella* forms, like *R. simplex* (Z. Mikh.) and *R. paragregaria* (Raus.), and of a peculiar group consisting of *T.? subschwagerinoides* (Grozd.), *T.? uniensis* (Grozd.), *T.? fornicatus* (Kanmera). Rare representatives of the genus *Pseudofusulinoides*, for instance, *P. dissimilis* (Scherb.), appear at the same level.

Praepseudofusulina forms are abundant and diverse in the *konovalovae* Zone, where the newly appeared species are *P. netkatchensis* (Ketat), *P. propria* (I. Tchern.), *P. busulukensis* (Dobr.), *P. impercepta* (Jagof.), *P. saratovensis* (I. Tchern.), *P. urmarensis* (Scherb.), and others. The *Globifusulina* genus becomes more diverse in the zone and includes newcomers *G. versabile* (Bensh), *G. gracilis* (Sjom.), *G. ponderosa* (Alksne), *G. confinis* (Sjom.), and others.

The renewal is also evident in the genus *Schellwienia*, whose species characteristic of the *ancestralis* Zone, for instance, *S. porrecta* (Sjom.) and some others, become rare and then die out. They are replaced by *Schellwienia lilia* (Kon.) and *S.* aff. *cognata* (Kon.). In addition, rugosofusulininds of the group *Rugosofusulina aktjubensis* Raus are also characteristic of the zone, and representatives of the group *Anderssonites paraanderssoni* (Raus.) are still common. Thickness of the *Occidentoschwagerina konovalovae* Zone varies from 6.0 m in sections Nizhnyaya Gubakha and Most to 15.0 m in the stratotype section.

The upper boundary of the *Occidentoschwagerina konovalovae* (and of the Melekhov Horizon) is defined at the appearance level of primitive *Schwagerina* forms, such as *S. fusiformis* (Krot.), *S. poljarica* (Grozd.), *S. kumajica* (Scherb.), *S. belajaensis* (Grozd.), and others. This level determines the boundary between the Carboniferous and Permian (the base of the *Schwagerina vulgaris–Schwagerina fusiformis* Zone). New *Globifusulina* species *G. sphaeroidea* (Raus.), *G. nibelensis* (Vol.), *G. elliptica* (Vol.), and others appear at this level together with a peculiar endemic group of *Anderssonites cognatus* (Echlakov) and *Anderssonites gregarius* (Lee) replacing the group of *Anderssonites paraanderssoni* (Raus.) and *A. anderssoni* (Schell.). Peculiar in the basal schwagerinid zone are representatives of the genus *Benshella*, i.e., the group of *"Pseudofusulina" subnathorsti* (Lee).

CORRELATION OF FUSULINID ZONATION IN THE MELEKHOV HORIZON WITH THAT IN ADJACENT AREAS

According to data of Konovalova (1991) obtained in the southeastern Timan Ridge (Well 308, the Yuzhnyi Burkem site), the interval corresponding to the Melekhov Horizon is subdivided into two schwagerinid beds correlative with local zones of the Perm' region. The *Globifusulina robusta* Beds were distinguished by Konovalova on the basis of their assemblage consisting of *Globifusulina robusta* (Raus.), *G. raznicini* (Vol.), *G. vozhgalensis* (Raus.), *G. pomposa* (Sjom.), *G. pechorica* (Vol.), and others, which coexist with the group of *Anderssonites paraanderssoni* (Raus.). In the Perm' region, a similar schwagerinid assemblage is characteristic of the local *Occidentoschwagerina ancestralis* Zone, where it is more diverse at the species and generic rank than the assemblage of the Timan Ridge. *Occidentoschwagerina* and *Schellwienia* forms often play a significant part in the assemblage. Many species from the Perm' region, for instance, *Schellwienia emaciata* (Kon.), S. voseiensis (Kon.), *Globifusulina pechorica* (Vol.), *Triticites? nadezhdae* Grozd, and others, which were described earlier from sections of the Timan–Pechora province, suggest that these two regions were well connected in the Melekhov time of the Gzhelian Age.

The *Pseudofusulinoides kljasmicus* (Sjom.) Beds in the southeastern Timan Ridge correspond to the appearance level of *Pseudofusulinoides* forms and yield abundant *Praepseudofusulina* species, such as *Praepseudofusulina saratovensis* (Tchern.), *P. ikensis* (Dobrokh.), and others. This subdivision is correlative with the *Occidentoschwagerina konovalovae* Zone of the Perm' region (Konovalova, 1991).

In the southern Urals, the interval corresponding to the Melekhov Horizon is divided into two zones (Popov *et al.*, 1985; Davydov and Popov, 1986; Davydov, 1986). The *Daixina (Bosbytauella) postsokensis* Zone of the Urals corresponds to the *Occidentoschwagerina ancestralis* Zone of the Perm' region. The lower boundary of the Uralian zone is established at the appearance level of *Globifusulina robusta* (Rauser), *G. vozhgalensis* (Rauser), and *Occidentoschwagerina* forms similar to *O. ancestralis* Echlakov, and others. *Daixina (Bosbytauella)* species from this zone are typical of the Tethyan sections, being unknown in the central Urals.

In the southern Urals, representatives of *Rugosochusenella* and the group of *Triticites? fornicatus* Kanmera appear at the base of the *Daixina (Bosbytauella) postgalloway* Zone (Popov *et al.*, 1985; Davydov and Popov, 1986). Accordingly, we may correlate the *postgalloway* Zone of the southern Urals with the *Occidentoschwagerina konovalovae* Zone of the Perm' region. *Occidentoschwagerina* forms suggest the same correlation: species *Occidentoschwagerina sarykumensis* Scherbovich sensu Davidov, 1986 and *O. sartauensis* (Davidov) (Davydov, 1986), the former similar to *Occidentoschwagerina konovalovae* Vilesov from the central Urals, were found in the *Daixina (Bosbytauella) postgalloway* Zone of the southern Urals.

According to data of Semina (1961), schwagerinid assemblages from beds in the Oka-Tsna Rampart are similar to fauna characterizing both local zones of the Melekhov Horizon in the Perm' region. For instance, the schwagerinid assemblage mostly consisting of *Globifusulina pomposa* (Sjom.) is distinguished in the Exposure 111 near the village of Golyshevo and marks

an interval of the section, which can be correlated with the *Occidentoschwagerina ancestralis* Zone. Exposure 114 above the Exposure 111 yielded abundant specimens of *Pseudofusulinoides kljasmicus* (Sjom.) in association with *Globifusulina pomposa* (Sjom.) and *Anderssonites pseudoanderssoni* (Sjom.). Consequently, this interval is correlative with the *Occidentoschwagerina konovalovae* Zone of the Perm' region.

Makhlina and Isakova (1997) published additional data interesting for correlation. In particular, *Occidentoschwagerina insolita* (Isakova) was described as *Daixina* form more advanced in phylogeny and belonging to subspherical occidentoschwagerins. The appearance of similar *Occidentoschwagerina* forms in sections of the Perm' region is confined to the *Occidentoschwagerina konovalovae* Zone. Similar *Occidentoschwagerina* species, for instance, *Occidentoschwagerina sartauensis* (Davidov) and others, appear at the same level in sections of the southern Urals (Davydov, 1986). In the Oka-Tsna Rampart, *Occidentoschwagerina insolita* (Isakova) is found in the upper part of the Melekhov Horizon and in the lower part of the Kholodnyi Log Horizon. This allows the *Occidentoschwagerina konovalovae* Zone of the Perm' region to be arbitrarily correlated with upper beds of the Melekhov Horizon, which also yield *Occidentoschwagerina insolita* (Isakova). It is significant that the endemic schwagerinid assemblage from the Melekhov Horizon of the Oka-Tsna Rampart is impoverished, as compared to that of the Urals, and zones that were distinguished in the Perm' region cannot be easily recognized here.

Beds comparable with the *Occidentoschwagerina ancestralis* Zone are hardly traceable in the Yablonevyi Ovrag section of the Samarskaya Luka site. It is likely that coeval sediments are represented here by dolomite beds 35b and 36a (after Murav'ev *et al.*, 1983) underlying marl beds with abundant schwagerinid fauna represented by *Praepseudofusulina orenburgensis cognata* (Ketat), *P. netkatchensis* (Ketat), *P. ustzajensis* (Malk.), and others. Fauna of this kind is characteristic of the *Occidentoschwagerina konovalovae* Zone (Bed 36b; Murav'ev *et al.*, 1983,1984; Kalmykova and Kashik, 1988).

According to data on sections in the Volgograd area, the Volga region (Zolotukhina and Ketat, 1984), *Praepseudofusulina* forms are rare in the lower part of the *Daixina* (*Bosbytauella*) *bosbytauensis–Globifusulina robusta* Zone, or in *Bosbytauella bosbytauensis* (Bensh) Beds according to local nomenclature. They become abundant upwards in the section, and this suggests that analogs of the *Occidentoschwagerina konovalovae* and *Occidentoschwagerina ancestralis* zones could be distinguished in this area as well.

CONCLUSION

Thus, the study on stratigraphic ranges and history of fusulinids shows that, in the Perm' region, the Melekhov Horizon of the Gzhelian Stage can be divided into two local subdivisions: the lower *Occidentoschwagerina ancestralis* and upper *Occidentoschwagerina konovalovae* zones. Both zones are found to extend to the southern Timan Range and correlate with the local *Daixina (Bosbytauella) postsokensis* and *Daixina (Bosbytauella) postgalloway* zones of the southern Urals. Analogous zones can be distinguished, though less confidently, in the platform sections of central Russia. The *Occidentoschwagerina* forms chosen as index species of zonal units of the Melekhov Horizon provide the phylogenetic substantiation for the Carboniferous–Permian boundary, because the *Schwagerina* index species for the Asselian biozonation seem to be the direct descendants of the genus *Occidentoschwagerina.*

Reviewers A.S. Alekseev and N.V. Goreva

REFERENCES

Chernykh, V.V., Biochronological Scales and Zonal Stratigraphy, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 100–110.

Davydov, V.I., Fusulinids of the Upper Carboniferous and the Asselian Stage of the Lower Permian in the Southern Urals, in *Pogranichnye otlozheniya karbona i permi Urala, Priural'ya i Srednei Azii* (The Carboniferous–Permian Boundary Beds of the Urals, Ural Area, and Central Asia), Moscow: Nauka, 1986, pp. 77–103.

Davydov, V.I., Subdivision and Correlation of the Upper Carboniferous–Lower Permian Deposits in the Donbass and the Donets Foredeep on the Basis of Fusulinids, *Sov. Geol.*, 1992, no. 5, pp. 53–61.

Davydov, V.I. and Popov, A.V., The Upper Carboniferous–Lower Permian Sections in the Southern Urals, in *Pogranichnye otlozheniya karbona i permi Urala, Priural'ya i Srednei Azii* (The Carboniferous–Permian Boundary Beds of the Urals, Ural Foredeep, and Central Asia), Moscow: Nauka, 1986, pp. 29–33.

Ekhlakov, Yu.A. and Zolotova, V.P., The Carboniferous–Permian Boundary Sections at the Kos'va and Berezovaya Rivers, in *Pogranichnye otlozheniya karbona i permi Urala, Priural'ya i Srednei Azii* (The Carboniferous–Permian Boundary Beds of the Urals, Ural Foredeep, and Central Asia), Moscow: Nauka, 1986, pp. 12–18.

Kalmykova, M.A., The Late Gzhelian and Early Asselian Paleobiogeography of the European USSR, *Vopr. Mikropaleontol.*, 1980, no. 23, pp. 39–51.

Kalmykova, M.A. and Kashik, D.S., Lower Permian Deposits of the Northern Russian Platform, in *Nizhnepermskie otlozheniya* (The Lower Permian Deposits), Perm: Perm Univ., 1974, pp. 45–47.

Kalmykova, M.A. and Kashik, D.S., Carboniferous–Permian Stratigraphy of the "Yablonevyi Ovrag" Section (Samarskaya Luka, Kuibyshev Area), *Ezhegod. Vses. Paleontol. O–va*, 1988, vol. 31, pp. 271–276.

Konovalov, M.V., *Stratigrafiya i fuzulinidy verkhnego karbona i nizhnei permi Timano-Pecherskoi neftegazonosnoi provintsii* (The Upper Carboniferous–Lower Permian Stratigraphy and Fusulinids from the Timan–Pechora Oil-and-Gas Province), Moscow: Nedra, 1991.

Makhlina, M.Kh. and Isakova, T.N., The Melekhovo Horizon: A New Stratigraphic Unit of the Gzhelian Stage, Upper Carboniferous (East European Platform), *Stratigr. Geol. Korrelyatsiya*, 1997, vol. 5, no. 5, pp. 44–53.

Murav'ev, I.S., Ermoshkin, N.V., and Shulikov, E.S., *Verkhnekamennougol'nye i nizhnepermskie otlozheniya Samarskoi Luki* (The Upper Carboniferous-Lower Permian Deposits of the Samarskaya Luka), Kazan: Kazan Univ., 1983.

Murav'ev, I.S., Grigor'eva, A.D., Gizatulin, Z.Z., *et al.*, The "Yablonevyi Ovrag" Section (Samarskaya Luka) as a Hypostratotype of the Gzhelian Stage and a Possible Carboniferous–Permian Boundary Stratotype, *Verkhnii karbon SSSR* (The Upper Carboniferous of the USSR), Moscow: Nauka, 1984, pp. 26–42.

Permian System: Guides to Geological Excursions in the Uralian Type Localities, Chuvashov, B.I., *et al.*, Eds., Occasional Publications ESRI, New Series, no 10, Columbia: Univ. South Carolina, 1993.

Pogranichnye otlozheniya karbona i permi Urala, Prikural'ya i Srednei Azii (biostratigrafiya i korrelyatsiya) (The Carboniferous–Permian Boundary Beds of the Urals, Ural Foredeep, and Central Asia: Biostratigraphy and Correlation), Moscow: Nauka, 1986.

Popov, A.P., Davydov, V.I., Donakova, L.M., and Kossovaya, O.L., Gzhelian Stratigraphy of the Southern Urals, *Sov. Geol.*, 1985, no. 3, pp. 57–67.

Postanovleniya Mezhvedomstvennogo stratigraficheskogo komiteta i ego postoyannykh komissii (Resolutions of the Interdepartmental Stratigraphic Committee and Its Permanent Commissions), Leningrad: Vses. Geol. Inst., 1985, issue 22.

Postanovleniya MSK i ego postoyannykh komissii (Resolutions of the Interdepartmental Stratigraphic Committee and Its Permanent Commissions), Leningrad: Vses. Geol. Inst., 1992, issue 26.

Rauser-Chernousova, D.M. and Reitlinger, E.A., Application of the Ecosystem Analysis for Solving Problems of the Carboniferous Stratigraphy, *Vopr. Mikropaleontol.*, 1977, no. 19, pp. 3–15.

Rauser-Chernousova, D.M., Bensh, F.R., Vdovenko, M.V., *et al.*, *Spravochnik po sistematike foraminifer paleozoya (endotiroidy, fuzulinoidy)* (Handbook on Systematics of Paleozoic Foraminifers: Endothyrids, Fusulinids), Moscow: Nauka, 1996.

Semina, S.A., Stratigraphy and Foraminifers (Fusulinids) from the *Schwagerina* Horizon in the Oka–Tsna Upland, *Tr. Geol. Inst., Akad. Nauk SSSR*, 1961, no. 57, pp. 1–80.

Shcherbakov, O.A., Shestakova, M.F., Shcherbakova, M.V., *et al.*, *Putevoditel' stratigraficheskoi ekskursii po karbonu Urala. Zapadnyi sklon Srednego Urala. Kos'vinskii marshrut* (Excursion Guidebook to Carboniferous Stratigraphic Sections of the Urals. The Western Slope of the Middle Urals. The Kos'va Route), Perm: Perm Politekhn. Inst., 1972.

Shcherbakova, M.V., The Carboniferous–Permian Beds in the Ostanets Section at the Kos'va River, in *Pogranichnye otlozheniya karbona i permi Urala, Priural'ya i Srednei Azii* (The Carboniferous–Permian Boundary Beds of the Urals, Ural Foredeep, and Central Asia), Moscow: Nauka, 1986, pp. 18–21.

Shcherbakova, M.V. and Shcherbakov, O.A., Upper Carboniferous Deposits in the "Kamen' Plakun" Area at the Chusovaya River, in *Novye dannye po stratigrafii verkhnego paleozoya–nizhnego kainozoya Urala* (New Data on the Upper Paleozoic–Lower Cenozoic Stratigraphy of the Urals), Yekaterinburg: Ural Otd. Ross. Akad. Nauk, 1994, pp. 41–93.

Vilesov, A.P., Fusulinid Zonation in the Kholodnyi Log Horizon, the Cisurals Area near Perm and the Western Slope of Central Urals, in *Geologiya, i poleznye iskopaemye Zapadnogo Urala* (Geology and Mineral Deposits of the Western Urals), Perm: Perm Univ., 1997a, pp. 39–42.

Vilesov, A.P., Schwagerinids from the Kholodnyi Log Horizon of the Asselian Stage, the Lower Permian of the Cisurals Area near Perm, *Cand. Sc. (Geol.–Mineral.) Dissertation*, Perm: Perm Univ., 1997b.

Vilesov, A.P., Carboniferous–Permian Boundary Beds of the "Nizhnyaya Gubakha" Section in the Central Urals, *Vestn. Perm Univ., Ser. Geol.*, 1997c, no. 4, pp. 93–100.

Vilesov, A.P., Genesis and Systematic Position of the Genus *Sphaeroschwagerina* Miklukho-Maclay, 1956 (Foraminifera, Schwagerinida), *Paleontol. Zh.*, 1998, no. 5, pp. 3–12.

Vilesov, A.P., Systematic Position of "Swollen *Diaxina*" (Foraminifera, Schwagerinida, Group of *Daixina robusta* Rauser), *Paleontol. Zh.*, 1999, no. 5, pp. 20–22.

Zolotova, V.P. and Provorov, Yu.A., The Most Section, in *Putevoditel' ekskursii po nizhnepermskim otlozheniyam po rekam Kos've, Sylve i Kame, Permskaya oblast'* (Excursion Guide to the Lower Permian Sections at the Kos'va, Sylva and Kama Rivers, the Perm Area), Sofronitskii, P.A., Ed., Perm: Perm Univ., 1974, pp. 35–49.

Zolotukhina, G.P. and Ketat, O.B., Fusulinid Evolution across the Carboniferous–Permian Boundary of the Southeastern Russian Platform, *Verkhnii karbon SSSR* (The Upper Carboniferous of the USSR), Moscow: Nauka, 1984, pp. 43–47.

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 461–469. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 43–51.
Original Russian Text Copyright © 2000 by Ivanova.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Biogeographic Zoning of the Indian Ocean in the Late Mesozoic

E. V. Ivanova

Shirshov Institute of Oceanology, Russian Academy of Sciences, Nakhimovskii pr. 36, Moscow, 117851 Russia

Received July 14, 1998; in final form, November 17, 1999

Abstract—The climatic zoning and surface-water circulation patterns in the Indian Ocean are elucidated for four time-intervals of the Late Mesozoic on the basis of micropaleontological data and plate tectonic reconstructions available. The oldest marine deposits referred to the Late Triassic are penetrated by drilling in the Wombat Plateau. It is established that development of ancient Circum-Antarctic Current and Austral Biogeographic Province began in the Neocomian. The Tethyan and transitional provinces appeared in the mid-Cretaceous time. In the Late Cretaceous, the study region included the Tethyan (tropical), "subtropical," temperate, and Austral provinces. The gradual complication of biogeographic zoning and surface-water circulation in the ocean, as it was opening in the Late Mesozoic, depended on global climatic changes.

Key words: *Mesozoic, biogeographic zones, paleocirculation, Indian Ocean, deep-sea drilling holes*

INTRODUCTION

New data, micropaleontological included, obtained during deep-sea drilling in the Indian Ocean, Legs 116–123 of R/V *JOIDES Resolution*, elucidate the Mesozoic paleoceanology of the basin. The Indian Ocean emerged as a result of the Pangea breakup in the Late Jurassic (Scotese *et al.*, 1987), but the oldest age of oceanic crust in the ocean remains unknown as yet. Seafloor spreading between eastern and western Gondwana blocks commenced in the West Somali Basin probably about 165 Ma ago, and the same event took place between Australia and Hindustan 133.5 Ma ago in the Valanginian (Royer and Coffin, 1992; Scotese, 1991). Mesozoic deposits were encountered in holes drilled within tropical and subtropical latitudes and in the Kerguelen Plateau (Sigal, 1974; McGowran, 1974; Herb, 1974; Krasheninnikov and Basov, 1985; Gradstein, 1992, and others). The oldest (Late Triassic) marine carbonate sediments were penetrated by Holes 759–761 drilled in the Wombat Plateau. These sediments yielded pollen, spores, calcareous nannoplankton, foraminifers, ostracodes, and dinoflagellate cysts (Gradstein, 1992) that proves the relationship of the sea basin with the eastern Tethys. The abundance of microfossils in bottom sediments increases during the Mesozoic and their geographic range becomes wider in the course of the basin opening.

The presented schemes of Mesozoic biogeographic zoning and surface-water circulation in the Indian Ocean are based on my analysis and interpretation of micropaleontological (lists of species and genera of different groups of microfossils) and paleoceanological data available in deep-sea drilling reports and other publications. I considered four stratigraphic intervals corresponding to the terminal Late Jurassic, Neocomian, Aptian–Turonian, and Coniacian–Maastrichtian. Schemes for the Barremian, Turonian, and Maastrichtian terminating the last three intervals are plotted using the plate tectonic reconstructions for datums of 119, 84, and 64 Ma, which correspond to paleomagnetic anomalies M0, C34, and C28 (Royer and Coffin, 1992).

LATE JURASSIC

Agglutinated and secretory benthic foraminifers, as well as nannoplankton and inocerams were encountered in the 10-m sequence of the Upper Jurassic (Tithonian) deposits penetrated at Sites 261 and 765 in the Argo abyssal plain (Krasheninnikov, 1978; Kaminski *et al.*, 1992). Prevalence of agglutinated foraminifers and their species composition characterizes quiet habitat environments below the carbonate compensation depth (CCD). This is compatible with data of Gradstein, (1992), who calculated the following series of paleodepths values: 2834 m for the Kimmeridgian–Tithonian at the Site 765; 2439 m for the Tithonian at the Site 261, and 800 m for the late Valanginian at the Site 766. Nannoflora is represented here by cosmopolitan species associated with *Conusphaera mexicana minor* and *Watznaueria manivitae*, both of Tethyan affinity, albeit other Tethyan taxons are absent. Hence, this fauna was thermophilic but not typical of the Tethys. The Tithonian–Berriasian inocerams, which have been found as fragments in Hole 765 and as intact shells in Hole 766, are characteristic of all drilling sites around the Antarctic, and this suggests that the Exmouth–Argo basin had connections with epicontinental seas of southern Gondwana rather than with the Tethys (Baumgartner *et al.*, 1992).

Makhlina, M.Kh. and Isakova, T.N., The Melekhovo Horizon: A New Stratigraphic Unit of the Gzhelian Stage, Upper Carboniferous (East European Platform), *Stratigr. Geol. Korrelyatsiya*, 1997, vol. 5, no. 5, pp. 44–53.

Murav'ev, I.S., Ermoshkin, N.V., and Shulikov, E.S., *Verkhnekamennougol'nye i nizhnepermskie otlozheniya Samarskoi Luki* (The Upper Carboniferous-Lower Permian Deposits of the Samarskaya Luka), Kazan: Kazan Univ., 1983.

Murav'ev, I.S., Grigor'eva, A.D., Gizatulin, Z.Z., *et al.*, The "Yablonevyi Ovrag" Section (Samarskaya Luka) as a Hypostratotype of the Gzhelian Stage and a Possible Carboniferous–Permian Boundary Stratotype, *Verkhnii karbon SSSR* (The Upper Carboniferous of the USSR), Moscow: Nauka, 1984, pp. 26–42.

Permian System: Guides to Geological Excursions in the Uralian Type Localities, Chuvashov, B.I., *et al.*, Eds., Occasional Publications ESRI, New Series, no 10, Columbia: Univ. South Carolina, 1993.

Pogranichnye otlozheniya karbona i permi Urala, Priural'ya i Srednei Azii (biostratigrafiya i korrelyatsiya) (The Carboniferous–Permian Boundary Beds of the Urals, Ural Foredeep, and Central Asia: Biostratigraphy and Correlation), Moscow: Nauka, 1986.

Popov, A.P., Davydov, V.I., Donakova, L.M., and Kossovaya, O.L., Gzhelian Stratigraphy of the Southern Urals, *Sov. Geol.*, 1985, no. 3, pp. 57–67.

Postanovleniya Mezhvedomstvennogo stratigraficheskogo komiteta i ego postoyannykh komissii (Resolutions of the Interdepartmental Stratigraphic Committee and Its Permanent Commissions), Leningrad: Vses. Geol. Inst., 1985, issue 22.

Postanovleniya MSK i ego postoyannykh komissii (Resolutions of the Interdepartmental Stratigraphic Committee and Its Permanent Commissions), Leningrad: Vses. Geol. Inst., 1992, issue 26.

Rauser-Chernousova, D.M. and Reitlinger, E.A., Application of the Ecosystem Analysis for Solving Problems of the Carboniferous Stratigraphy, *Vopr. Mikropaleontol.*, 1977, no. 19, pp. 3–15.

Rauser-Chernousova, D.M., Bensh, F.R., Vdovenko, M.V., *et al.*, *Spravochnik po sistematike foraminifer paleozoya (endotiroidy, fuzulinoidy)* (Handbook on Systematics of Paleozoic Foraminifers: Endothyrids, Fusulinids), Moscow: Nauka, 1996.

Semina, S.A., Stratigraphy and Foraminifers (Fusulinids) from the *Schwagerina* Horizon in the Oka–Tsna Upland, *Tr. Geol. Inst., Akad. Nauk SSSR*, 1961, no. 57, pp. 1–80.

Shcherbakov, O.A., Shestakova, M.F., Shcherbakova, M.V., *et al.*, *Putevoditel' stratigraficheskoi ekskursii po karbonu Urala. Zapadnyi sklon Srednego Urala. Kos'vinskii marshrut* (Excursion Guidebook to Carboniferous Stratigraphic Sections of the Urals. The Western Slope of the Middle Urals. The Kos'va Route), Perm: Perm Politekhn. Inst., 1972.

Shcherbakova, M.V., The Carboniferous–Permian Beds in the Ostanets Section at the Kos'va River, in *Pogranichnye otlozheniya karbona i permi Urala, Priural'ya i Srednei Azii* (The Carboniferous–Permian Boundary Beds of the Urals, Ural Foredeep, and Central Asia), Moscow: Nauka, 1986, pp. 18–21.

Shcherbakova, M.V. and Shcherbakov, O.A., Upper Carboniferous Deposits in the "Kamen' Plakun" Area at the Chusovaya River, in *Novye dannye po stratigrafii verkhnego paleozoya–nizhnego kainozoya Urala* (New Data on the Upper Paleozoic–Lower Cenozoic Stratigraphy of the Urals), Yekaterinburg: Ural Otd. Ross. Akad. Nauk, 1994, pp. 41–93.

Vilesov, A.P., Fusulinid Zonation in the Kholodnyi Log Horizon, the Cisurals Area near Perm and the Western Slope of Central Urals, in *Geologiya, i poleznye iskopaemye Zapadnogo Urala* (Geology and Mineral Deposits of the Western Urals), Perm: Perm Univ., 1997a, pp. 39–42.

Vilesov, A.P., Schwagerinids from the Kholodnyi Log Horizon of the Asselian Stage, the Lower Permian of the Cisurals Area near Perm, *Cand. Sc. (Geol.–Mineral.) Dissertation*, Perm: Perm Univ., 1997b.

Vilesov, A.P., Carboniferous–Permian Boundary Beds of the "Nizhnyaya Gubakha" Section in the Central Urals, *Vestn. Perm Univ., Ser. Geol.*, 1997c, no. 4, pp. 93–100.

Vilesov, A.P., Genesis and Systematic Position of the Genus *Sphaeroschwagerina* Miklukho-Maclay, 1956 (Foraminifera, Schwagerinida), *Paleontol. Zh.*, 1998, no. 5, pp. 3–12.

Vilesov, A.P., Systematic Position of "Swollen *Diaxina*" (Foraminifera, Schwagerinida, Group of *Daixina robusta* Rauser), *Paleontol. Zh.*, 1999, no. 5, pp. 20–22.

Zolotova, V.P. and Provorov, Yu.A., The Most Section, in *Putevoditel' ekskursii po nizhnepermskim otlozheniyam po rekam Kos've, Sylve i Kame, Permskaya oblast'* (Excursion Guide to the Lower Permian Sections at the Kos'va, Sylva and Kama Rivers, the Perm Area), Sofronitskii, P.A., Ed., Perm: Perm Univ., 1974, pp. 35–49.

Zolotukhina, G.P. and Ketat, O.B., Fusulinid Evolution across the Carboniferous–Permian Boundary of the Southeastern Russian Platform, *Verkhnii karbon SSSR* (The Upper Carboniferous of the USSR), Moscow: Nauka, 1984, pp. 43–47.

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 461–469. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 43–51.
Original Russian Text Copyright © 2000 by Ivanova.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Biogeographic Zoning of the Indian Ocean in the Late Mesozoic

E. V. Ivanova

Shirshov Institute of Oceanology, Russian Academy of Sciences, Nakhimovskii pr. 36, Moscow, 117851 Russia

Received July 14, 1998; in final form, November 17, 1999

Abstract—The climatic zoning and surface-water circulation patterns in the Indian Ocean are elucidated for four time-intervals of the Late Mesozoic on the basis of micropaleontological data and plate tectonic reconstructions available. The oldest marine deposits referred to the Late Triassic are penetrated by drilling in the Wombat Plateau. It is established that development of ancient Circum-Antarctic Current and Austral Biogeographic Province began in the Neocomian. The Tethyan and transitional provinces appeared in the mid-Cretaceous time. In the Late Cretaceous, the study region included the Tethyan (tropical), "subtropical," temperate, and Austral provinces. The gradual complication of biogeographic zoning and surface-water circulation in the ocean, as it was opening in the Late Mesozoic, depended on global climatic changes.

Key words: *Mesozoic, biogeographic zones, paleocirculation, Indian Ocean, deep-sea drilling holes*

INTRODUCTION

New data, micropaleontological included, obtained during deep-sea drilling in the Indian Ocean, Legs 116–123 of R/V *JOIDES Resolution*, elucidate the Mesozoic paleoceanology of the basin. The Indian Ocean emerged as a result of the Pangea breakup in the Late Jurassic (Scotese *et al.*, 1987), but the oldest age of oceanic crust in the ocean remains unknown as yet. Seafloor spreading between eastern and western Gondwana blocks commenced in the West Somali Basin probably about 165 Ma ago, and the same event took place between Australia and Hindustan 133.5 Ma ago in the Valanginian (Royer and Coffin, 1992; Scotese, 1991). Mesozoic deposits were encountered in holes drilled within tropical and subtropical latitudes and in the Kerguelen Plateau (Sigal, 1974; McGowran, 1974; Herb, 1974; Krasheninnikov and Basov, 1985; Gradstein, 1992, and others). The oldest (Late Triassic) marine carbonate sediments were penetrated by Holes 759–761 drilled in the Wombat Plateau. These sediments yielded pollen, spores, calcareous nannoplankton, foraminifers, ostracodes, and dinoflagellate cysts (Gradstein, 1992) that proves the relationship of the sea basin with the eastern Tethys. The abundance of microfossils in bottom sediments increases during the Mesozoic and their geographic range becomes wider in the course of the basin opening.

The presented schemes of Mesozoic biogeographic zoning and surface-water circulation in the Indian Ocean are based on my analysis and interpretation of micropaleontological (lists of species and genera of different groups of microfossils) and paleoceanological data available in deep-sea drilling reports and other publications. I considered four stratigraphic intervals corresponding to the terminal Late Jurassic, Neocomian, Aptian–Turonian, and Coniacian–Maastrichtian. Schemes for the Barremian, Turonian, and Maastrichtian terminating the last three intervals are plotted using the plate tectonic reconstructions for datums of 119, 84, and 64 Ma, which correspond to paleomagnetic anomalies M0, C34, and C28 (Royer and Coffin, 1992).

LATE JURASSIC

Agglutinated and secretory benthic foraminifers, as well as nannoplankton and inocerams were encountered in the 10-m sequence of the Upper Jurassic (Tithonian) deposits penetrated at Sites 261 and 765 in the Argo abyssal plain (Krasheninnikov, 1978; Kaminski *et al.*, 1992). Prevalence of agglutinated foraminifers and their species composition characterizes quiet habitat environments below the carbonate compensation depth (CCD). This is compatible with data of Gradstein, (1992), who calculated the following series of paleodepths values: 2834 m for the Kimmeridgian–Tithonian at the Site 765; 2439 m for the Tithonian at the Site 261, and 800 m for the late Valanginian at the Site 766. Nannoflora is represented here by cosmopolitan species associated with *Conusphaera mexicana minor* and *Watznaueria manivitae*, both of Tethyan affinity, albeit other Tethyan taxons are absent. Hence, this fauna was thermophilic but not typical of the Tethys. The Tithonian–Berriasian inocerams, which have been found as fragments in Hole 765 and as intact shells in Hole 766, are characteristic of all drilling sites around the Antarctic, and this suggests that the Exmouth–Argo basin had connections with epicontinental seas of southern Gondwana rather than with the Tethys (Baumgartner *et al.*, 1992).

NEOCOMIAN

Small oceanic basins surrounded by land emerged owing to the earliest Neocomian sea-floor spreading between Australia and India. A weak circulation and stagnant conditions of bottom waters contaminated with hydrogen sulfide (at least near Australia) were typical of those basins that resulted in preservation of agglutinated foraminifers only (Veevers and Heirtzler, 1974; Krasheninnikov and Basov, 1985). As sea-floor spreading kept on opening of the Indian Ocean, a deep-water strait emerged in the Hauterivian–Barremian time between Hindustan and Antarctica, which is evident from lithological (Zharkov *et al.*, 1998a) and micropaleontological data. The deep-water environment in the West Australian Basin of the Barremian time is inferable on the basis of calcareous nannoplankton and dinoflagellates from Hole 263 (Krasheninnikov, 1978; Burky, 1974), although Proto Decima (1974) suggested the redeposited status of these microfossils. Nevertheless, drilling results of Leg 122 showed that the Neocomian and Barremian deposits are definitely present in the Exmouth and Wombat plateaus, where corresponding assemblages of dinoflagellates and calcareous nannoplankton were distinguished at Sites 762–763 (Bralower and Siesser, 1992; Brenner, 1992).

Judging from extremely poor Barremian assemblages of agglutinated foraminifers from Sites 765 and 261 (Kaminski *et al.*, 1992), the deep water exchange with the Tethys developed across the Argo abyssal plain. Paleontological and tectonic data show however that the Neocomian Argo Basin did not represent a part of the Tethys. A weak influence of the latter and close relations of plankton assemblages with high latitudes are well established here (Baumgartner *et al.*, 1992). In particular, the composition of radiolarian and nannoplankton assemblages from Sites 765–766 (the mixed Austral and Tethyan faunas) indicates that a marine passage opened between the Circum-Antarctic region and Argo Basin in the Berriasian to trigger the water influx from southern high-latitude areas. In the late Valanginian–Hauterivian deposits, typical Tethyan species are almost absent, except for some tolerant taxa, but the change of acme zones (flourish zones) of some high-latitude species is clearly recognized in this interval. This likely indicates emergence of the southern high-latitude Austral faunal province.

The Circum-Antarctic Current apparently set in motion since the Valanginian, when the Antarctic Peninsula has not yet been separated from South America (Scotese *et al.*, 1987; Baumgartner *et al.*, 1992). The Circum-Antarctic Current of that time could bring cold-resistant radiolarian species via the Exmouth Plateau to the Argo Basin, and, as a result of upwelling near the continental slope of Australia, the taxons arrived at warm surface waters to perish there. The Circum-Antarctic Current became wider in the Barremian (Fig. 1), and this probably lowered the surface water temperature in the Argo Basin, smoothing out the effect of latitudinal temperature zoning. Connections with the southern Tethys opened at the same time, and typical representatives of Tethyan microfaunas appeared in the Argo Basin and on the Exmouth Plateau. Climatic conditions were more stable, although position of the region was more advanced toward the high latitudes as compared to that in the earliest Neocomian. The species composition of nannoflora changed greatly suggesting the onset of open-ocean conditions at the transition between the Barremian and Aptian (Baumgartner *et al.*, 1992).

The Early Cretaceous microfossils from Australian, Antarctic, and East Indian regions were represented by cold-resistant (with Austral elements) but not Tethyan forms. This was probably a response to the Gondwana breakup and formation of the initial Circum-Antarctic Current (Baumgartner *et al.*, 1992; Stevens, 1980).

Neocomian microfossils from the western Indian Ocean (Hole 249) are represented mainly by benthic lagenids and ostracodes (Krasheninnikov and Basov, 1985). The Early Cretaceous (Berriasian–Hauterivian) belemnite *Duvalia* cf. *D. sakalava* from Site 766 of the Gascogne Abyssal Plain evidences in favor of the Circum-Antarctic transportation from the Madagascar Island, where similar belemnites are known (Baumgartner *et al.*, 1992). Sigal (1974) pointed to the thermophilic nature of the Neocomian foraminifer assemblage from Madagascar and the Mozambique Ridge (Site 249), as well as to the sea transgression on the southwestern African coast.

The Neocomian flora from Antarctic Peninsula and southern Australia suggests strong seasonal contrasts of regional climate, when temperatures below zero were typical of long dark winters. Biogeographic changes are especially contrast southward of the latitude 40°S (Baumgartner *et al.*, 1992).

Thus, in the Barremian, the Indian Ocean small in area at that time was probably located inside the high-latitude Austral biogeographic province. The proto-Circum-Antarctic current circulated in the ocean, and the anticyclonic gyre in the northeast, at the boundary with the Tethys (Fig. 1), controlled the water exchange between two oceans. Zharkov *et al.*, (1998a) published reconstructions, where the Indian Ocean is included into the middle-latitude humid belt of coal and kaolinite accumulation, whereas the larger part of Antarctica and southern Australia are shown as parts of the southern humid belt of coal accumulation.

MID-CRETACEOUS

The published global reconstructions of mid-Cretaceous climatic belts (Chumakov *et al.*, 1995) show a southern arid zone in the northern part of the Indian Ocean and the middle-latitude warm and humid zone located southward. Huber *et al.*, (1995) consider the early Turonian as corresponding to the climatic optimum, when the sea-level stand was highest in compar-

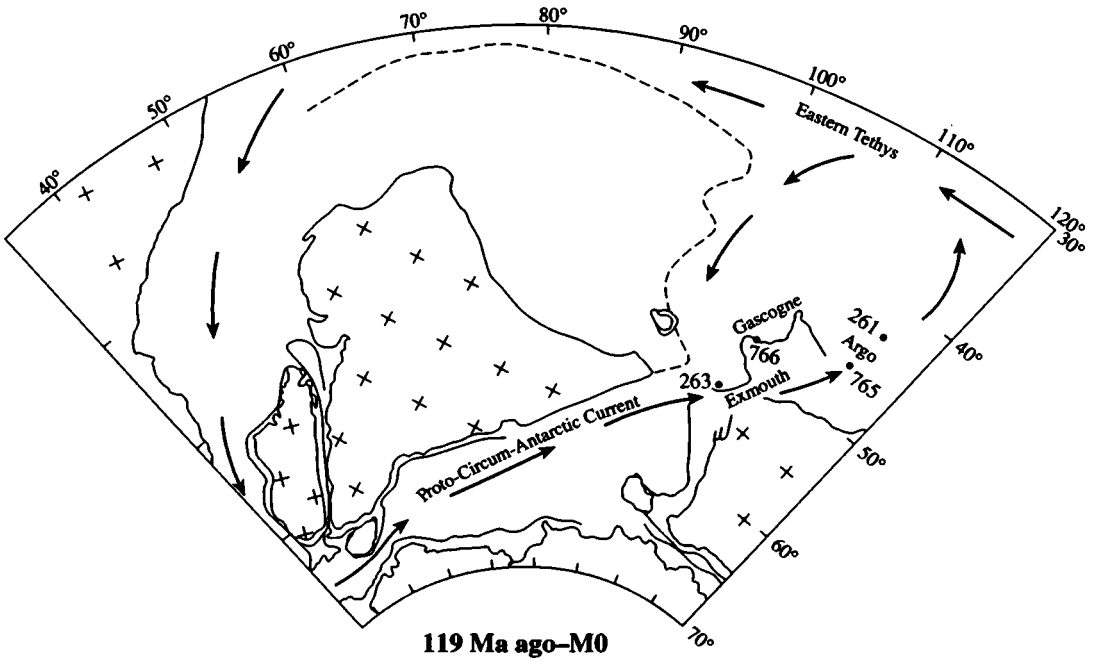


Fig. 1. Scheme illustrating the Early Cretaceous currents in the Indian Ocean and its connections with the Tethys (modified after Baumgartner *et al.*, 1992; the plate tectonic model and bathymetry at the time of magnetic anomaly M0, 119 Ma ago, are from Royer and Coffin, 1992). Continuous lines outline the shelf edge, 2000-m and 4000-m depth contours; the hypothetical boundary of Great India is shown by dotted line; dots mark the inferred position of deep-sea drilling sites; arrows denote the direction of currents.

ison with other Cretaceous ages. Micropaleontological data suggest that three biogeographic provinces appeared during the Middle Cretaceous (Fig. 2a): Tethyan, tropical Austral with a transitional zone, and subtropical Temperate (Krasheninnikov and Basov, 1985). The provinces differed greatly in composition and abundance of microfossil groups, in particular, of planktonic foraminifers.

The Tethyan foraminifer assemblages are known from northern Australia and Papua–New Guinea shelf zone. They inhabited shallow epicontinental basins well-heated by warm currents (Krasheninnikov and Basov, 1985).

Since the Albian, diverse assemblages of planktonic foraminifers typical of 30s degrees in the south populated the Exmouth and Wombat plateaus. Deposits of the Coniacian–late Turonian *Falsotruncana maslakovae* Zone are much more thick at the Site 762 than at Sites 761B and 763. The assemblage of planktonic foraminifers includes here the zonal index species, *Dicarinella imbricata, Whiteinella archaeocretacea,* and *Marginotruncana marianosi.* The last three taxa are also typical of the middle Turonian *Helvetoglobotruncana helvetica* Zone. Wonders (1992) regarded this fauna as displaying Tethyan affinity. The well-preserved Albian–Cenomanian nannoplankton exemplifies fauna of the temperate climatic zone and includes both the Austral and Tethyan elements. Minor fluctuations in abundance of both provincial groups across the mentioned time interval indicate that Site 763 was located in a stable gyre area. Variability of thermophilic affinity of foraminifer and nannoplankton assemblages is assumed to reflect difference in depth ranges of their habitats (Bralower and Siesser, 1992). In my opinion, it seems more logical to assume that a warm current from the Tethys running along the Hindustan and a cold branch of the proto-Circum-Antarctic current (West Australian current) set in motion the anticyclonic gyre in the northern part of the ocean during the Turonian (Fig. 2a). That gyre promoted migration of Tethyan foraminifers to the Exmouth Plateau, whereas nannoplankton of the Austral province was transported by the West Australian current. It represented an element of a larger anticyclonic gyre controlled by one stream passing along Africa from the Tethys and by the proto-Circum-Antarctic current.

The cold-resistant elements of nannoplankton, for instance, *Crucibiscutum salebrosum* and *Seribiscutum primitivum* from the Argo Basin (Sites 765–766), indicate influence of the Austral faunal province located in higher latitudes. Nevertheless, the control of Tethyan biota that increased in mid-Cretaceous is evident in all microfossil groups, even in those where taxons of high latitudes are steadily present. The Argo Basin occupied a transitional position between the Austral and Tethyan provinces. The Aptian–Albian nannoplankton is represented here mainly by cosmopolitan species (Baumgartner *et al.*, 1992).

A sharp decrease in the species diversity of planktonic foraminifers at the Site 258 (the Naturaliste Pla-

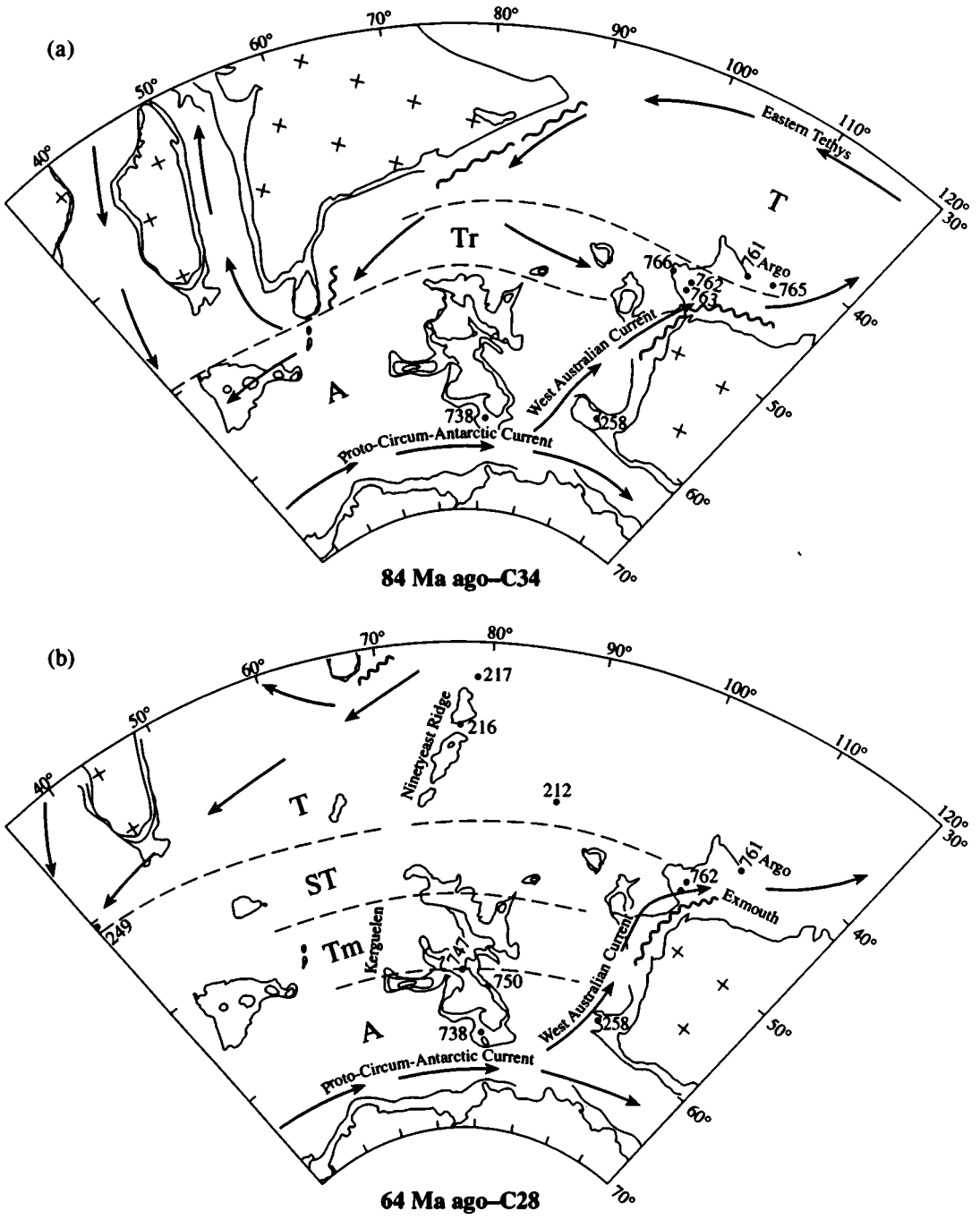


Fig. 2. The biogeographic zoning and surface-water currents in the Indian Ocean during the Turonian (a) and Maastrichtian (b). Zones: (T) Tethyan or tropical, (ST) subtropical, (Tr) transitional, (Tm) temperate, (A) Austral province. The plate tectonic base with paleobathymetry for Chron C34, about 84 Ma ago (a), for Chron C28, about 64 Ma ago (b), from (Royer and Coffin, 1992). Thin lines indicate the position of the shelf edge and 2000-m and 4000-m depth contours, dots show the reconstructed position of deep-sea drilling holes, hatched lines exhibit boundaries between provinces, arrows display the direction of currents, sinusoid lines illustrate the position of upwellings.

teau), as compared to Site 766 (the Gascogne Basin) located about 10° northward, indicates a high gradient of the surface-water temperature in the Albian basin. Late Aptian–early Albian radiolarians point to a high-productive upwelling near the northwestern coast of Australia that was associated with a current passing parallel to the coast and/or with winds blowing from land (Baumgartner *et al.*, 1992). The oceanic basin with the northward water transportation system along the coast existed west of Australia already since the Cenomanian (Veevers and Heirtzler, 1974; Krasheninnikov and Basov, 1985).

In the western part of the ocean, the boundary between the transitional zone and Austral province was

located, at least since the Aptian, south of Africa in the proximity to Site 249.

The Austral assemblages of planktonic foraminifers are known from the Kerguelen Plateau, Broken Ridge, abyssal plain west of Australia, Wharton Basin, southern Australia, Yukla Basin, and from the southern part of the Great Artesian Basin (Quilty, 1973; Herb, 1974; McGowran, 1974; Krasheninnikov, 1978). These are the so-called *Globigerinelloides–Hedbergella–Heterohelix* assemblages. Krasheninnikov and Basov (1985) pointed out that the Austral fauna from the Kerguelen Plateau is more thermophilic than that of the Naturaliste Plateau, because position of the latter was in higher latitudes during the mid-Cretaceous. The Turonian foraminifer assemblages from the Site 258 includes, in addition to *Hedbergella* forms, the abundant keeled representatives of the thermophilic genus *Praeglobotruncana* (Herb, 1974). It is established on the basis of oxygen isotope systematics for the Albian time that the surface-water temperature in the region was 15°C (Huber *et al.*, 1995). In the upper Cenomanian–Turonian deposits of the Kerguelen Plateau, cold-resistant *Hedbergella* and *Globigerinelloides* dominate but coexist with thermophilic *Schackoina, Rotalipora, Praeglobotruncana*, and *Globotruncana* (Quilty, 1973; Krasheninnikov and Basov, 1985). The Austral *Thiersteinia ecclesiastica* nannoplankton assemblage (Watkins, 1992) and assemblage of planktonic foraminifers transitional between the Austral and subtropical faunas (Quilty, 1992a) were identified in the upper Turonian and lower Coniacian deposits at the Site 747.

The predominance of *Gavelinella eriksdalensis* among poorly preserved benthic foraminifers likely suggests the upper-middle bathyal depth in the northern part of the Kerguelen Plateau (Quilty, 1992b), whereas the western plateau part corresponded to neritic zone. In the Turonian, the Site 755 of the Broken Ridge was located in the upper bathyal zone (Pospichal *et al.*, 1992). The Turonian–early Campanian poorly preserved nannoplankton was found at that site (Risawati, 1991).

Data discussed above elucidate the complex latitudinal biogeographic zoning in the Indian Ocean of the mid-Cretaceous time, where anticyclonic gyres of different scale were also in action. The warm water moved into the tropical zone from the Pacific via the eastern Tethys, whereas the proto-Circum-Antarctic current delivered the cold water from the South Atlantic Ocean. The above-mentioned tendency to more complicated climatic zoning is also evident from continental paleogeographic reconstructions (Chumakov *et al.*, 1995; Zharkov *et al.*, 1995).

THE TERMINAL CRETACEOUS (MAASTRICHTIAN)

Warming that lasted since the Early Cretaceous until the Campanian was replaced by cooling (Huber *et al.*, 1995; Sliter, 1995). Within south latitudes of 60s degrees, the surface-water temperature dropped at the end of the Cretaceous from 24°C characterizing the Coniacian–Santonian interval to 10–13°C (Barrera and Huber, 1990; Huber *et al.*, 1995). The Maastrichtian is recognized as an age of very sharp global cooling related to the rearrangement of surface and bottom water circulation systems, when, probably in the late Albian, shallow straits appeared between South America and Antarctic Peninsula, and in the Campanian, between Australia and Antarctica, and maybe between western and eastern Australia (Veevers and Heirtzler, 1974; Krasheninnikov and Basov, 1985; Scotese *et al.*, 1987; Barron, 1987; Scotese, 1991; Huber and Watkins, 1992; Sliter, 1995; Zharkov *et al.*, 1998b). Systematics of oxygen isotope data for planktonic foraminifers and calcareous nannoplankton from Sites 217 and 212 suggests cooling by 3–4°C during the Maastrichtian and subsequent warming by 2°C at the boundary between the Cretaceous and Paleogene. Data on carbon isotope distribution indicate a substantial decrease in the surface water productivity at the end of the Cretaceous (Oberhansli, 1986; Nomura, 1992).

The Upper Maastrichtian deposits (the *Abathomphalus mayaroensis* Zone of planktonic foraminifers and the *Nephrolithus frequens* Zone of calcareous nannoplankton) are known the Ninetyeast (Sites 216, 217, and 758) and Mozambique ridges (Krasheninnikov, 1978; van Eijden and Smit, 1991; Resiwati, 1991). Tropical assemblages of planktonic foraminifers from Site 217, which developed under open-sea conditions, are more diverse than those from Site 216 (they include almost all species of one- and two-keeled *Globotruncana* forms and almost all morphological varieties of the genus *Heterohelix* despite a great influence of selective dissolution in the first drilling hole). Hence, there is the biogeographic diversity gradient between these two sites (Gartner *et al.*, 1974; McGowran, 1974). The composition of benthic foraminifers indicate the shelf depth the Site 216 that experienced subsidence in the late Maastrichtian (McGowran, 1974). Tropical assemblages of planktonic foraminifers are also known from New Guinea and the northern Carnarvon Basin (the latitude of 23°S). At the same time, many tropical species of foraminifers and nannoplankton are unknown from western Australia (Gartner *et al.*, 1974).

The subtropical fauna of planktonic foraminifers associated with some tropical species characterizes the Campanian–Maastrichtian deposits at Site 249 (Krasheninnikov and Basov, 1985; see Fig. 2b).

On the Exmouth Plateau, planktonic foraminifers of the upper Maastrichtian *Abathomphalus mayaroensis* Zone (Holes 761B and 762) are represented by its zonal species associated with cold-resistant *Heterohelix* spp., *Rugoglobigerina* spp., *Globigerina arca, Pseudotextularia elegans, Racemiguembelina fructicosa, Gublerina cuvillieri*, and also with less abundant and more thermophilic *Globotruncana rosetta* and *Globotrun-*

canita spp. Keeled species are dispersed throughout the zone, but their diversity increases from the base upward reflecting the increasing influence of the Tethys during the middle–late Maastrichtian (Wonders, 1992). The Santonian–Maastrichtian calcareous nannoplankton assemblage from the Exmouth Plateau (Holes 762 and 763) differs greatly in composition from that of Site 761 located only 3° northward. Probably, there was a high thermal gradient between the sites in the Late Cretaceous time (Bralower and Siesser, 1992).

The late Maastrichtian assemblage of planktonic foraminifers from the Broken Ridge (Site 752) includes many thermophilic species represented, as a rule, by few specimens which suggests the temperate or cool subtropical climate. On the other hand, the middle–late Maastrichtian nannoplankton is poorly preserved here (Sites 752 and 754) and similar in composition to the nannoplankton assemblages of the Austral province and Kerguelen Plateau (van Eijden and Smit, 1991).

Foraminifers from Upper Cretaceous deposits at Site 255 are represented by relatively cold-resistant *Hedbergella* and *Globigerinelloides* forms. The Coniacian–Santonian planktonic foraminifers from the Naturaliste Plateau (Site 258) are characterized by a low species diversity. Dominant among them are cold-resistant representatives of genera *Hedbergella, Heterohelix, Globigerinelloides, Archaeoglobigerina,* and *Whiteinella* all having no keel (Herb, 1974). Pospichal *et al.* (1992) estimated, on the basis of benthic foraminifers, the paleodepth value of 1000 m (the middle–lower bathyal zone) for Site 752 of the Broken Ridge. The ridge was uplifted in the Late Cretaceous (Krasheninnikov and Basov, 1985). Several species of benthic foraminifers became extinct at the level 2 m above the Cretaceous–Paleogene boundary, where a sharp decrease in the diversity of planktonic foraminifers was also noted. This indicates that environmental changes in the surface water layer and at the ocean bottom were separated by a time interval (Nomura, 1992). Quickly dying out among benthic foraminifers are first of all those that strongly depend on the primary productivity reduction and, to a lesser extent, the detritus-consuming species (Arthur *et al.*, 1987; Nomura, 1992).

Paleontology of upper Coniacian–Maastrichtian deposits of the Kerguelen Plateau is well studied, especially at Site 750, where drilling recovered the 177.3-m-long core section, the most complete one in the southern hemisphere (Watkins *et al.*, 1992). The late Campanian–early Maastrichtian calcareous nannoplankton and foraminifers from Sites 750 and 747 are undoubtedly of the Austral origin. In contrast, the late Maastrichtian nannoplankton of the Austral type is found here in association with with very diverse transitional assemblages of planktonic foraminifers, which include such thermophilic genera as *Globotruncana, Gublerina,* and *Recemiguembelina* (Quilty, 1992a; Watkins, 1992).

A similar increase in abundance of Tethyan elements was noted in the late Maastrichtian assemblage from the Weddell Sea (Huber, 1990). Taking into account the Austral origin of nannoplankton and oxygen isotope data for planktonic foraminifers that indicate the temperature decrease down to 10–13°C at the end of the Cretaceous (Barrera *et al.*, 1987; Barrera and Huber, 1990; Huber *et al.*, 1995), Huber (1990, 1991) argued that the presence of "transitional" foraminifer assemblage was conditioned by some other ecological factor rather than by water temperature. It seems plausible that thermophilic foraminifers could be transported from subtropical latitudes by the western branch of the anticyclonic gyre, which, according to the reconstruction of Levitan (1992), passed near the Kerguelen Plateau. Watkins *et al.* (1992) believe that the ecological differentiation of cold-resistant and moderately thermophilic nannoplankton assemblages occurred in the central part of the Kerguelen Plateau during the period corresponding to the middle Campanian hiatus in sedimentation. Assemblages of nannoplankton and planktonic foraminifers from the southern margin of the plateau (Site 738) show the low species diversity. Five foraminifer species (*Hedbergella sliteri, Globogerinelloides impensus, Archaeoglobigerina australis, A. mateola,* and *Rugotruncana circumnodifer*) are typical of, or even endemic for the Austral province. They suggest that southern areas of the Indian and Atlantic oceans have been connected (Huber, 1990, 1991; Wei and Thierstein, 1991).

The Maastrichtian benthic foraminifers show that the eastern margin of the Kerguelen Plateau (Site 750) was located in the middle–upper bathyal zone (Quilty, 1992b; Watkins *et al.*, 1992). The northern part of the plateau (Site 747) subsided at the late Campanian–early Maastrichtian boundary time down to the depth of 1000 m. The upper Maastrichtian volcaniclastic deposits are missing from this area. The upper Campanian–Maastrichtian microfossils from Site 748 (benthic foraminifers, dinoflagellates, and red algae) are inhabitants of shallow marine settings situated at the depth of about 20 m. Judging from benthic foraminifers from Site 738, Maastrichtian sedimentation developed below the shelf-break zone at the depth exceeding 500–600 m (Huber, 1991). In the Kerguelen Plateau (Site 738), in contrast to the Broken Ridge, the extinction of some Cretaceous benthic foraminifers is recorded within the upper three meters of the upper Maastrichtian sequence, whereas the keeled planktonic foraminifers become extinct in the upper two meters; age of these events has to be verified (Thierstein *et al.*, 1991).

Thus, the global cooling and further opening of the Indian Ocean in the Maastrichtian time were accompanied by the increase of the meridional thermal gradient, by further differentiation of biogeographic zones, and by enhanced surface-water circulation. In response to appearance of passages, which connected first the South Atlantic and Pacific oceans and later the Pacific and Indian oceans (Barron, 1987; Scotese, 1991) in the

high-latitude zone, the proto-Circum-Antarctic current approached its current patterns. At the same time, the warm Equatorial current kept on running from the Pacific into Indian Ocean between Hindustan and Australia and via the Mozambique–Somali Strait into the South Atlantic Ocean (Zharkov *et al.*, 1998b). The anticyclonic gyre spanned over the entire Indian Ocean and caused upwelling at the western and eastern peripheries. Smaller circulation systems were likely complicating the gyre.

CONCLUSION

The discussed reconstructions show that the biogeographic zoning in the Indian Ocean of the Mesozoic time differed substantially from that observable now. This conclusion is compatible with concept of the warm ice-free biosphere (Chumakov, 1995) at that stage of geologic history.

In the Late Jurassic, a marine basin probably existed only at the site of the Exmouth Plateau and adjacent Argo Basin, because rather thermophilic and deep-water microfossils are known from this area.

Basic Neocomian events correspond to formation and evolution of the proto-Circum-Antarctic current and to appearance of the Austral biogeographic province. The current promoted plankton migration from the high latitudes and, probably, from western oceanic areas into the Exmouth–Argo basin. The basins became connected with the southeastern Tethys at the end of the Neocomian owing to the anticyclonic gyre action in the surface water mass.

In the mid-Cretaceous and particularly during the Turonian climatic optimum, three biogeographic provinces formed. The Tethyan province occupied the Papua Basin and northern Australia, the transitional one spanned the Argo–Exmouth basin, and the Austral province engulfed the Kerguelen Plateau, Broken Ridge, and southern Australia. The system of surface-water circulation in the ocean that considerably increased in scale probably represented an anticyclonic gyre, the southern branch of which corresponded to the proto-Circum-Antarctic current, whereas the northern branch continued a warm current from the eastern Tethys. Smaller circulation systems existed within the major gyre, for instance, an anticyclonic current in the northeastern periphery of the ocean.

The Late Cretaceous climatic changes culminated in a considerable cooling of the Maastrichtian time probably replaced by a warming phase at the Cretaceous–Paleogene boundary. In the Maastrichtian, the thermophilic microfossil assemblages of the tropical (Tethyan) affinity developed in the northern part of the ocean (the Ninetyeast Ridge area), in the Papua–New Guinea Basin, and in northern Australia. The subtropical fauna presumably dominated in the Mozambique Ridge and the Exmouth Plateau areas, whereas assemblages of the temperate zone dwelt in the Broken Ridge area. The cold-resistant plankton of the Austral province coexisted with Tethyan elements in the southern part of the ocean and in the Kerguelen Plateau region. When the proto-Circum-Antarctic current, probably, closed up, the latitudinal differentiation of planktonic communities increased. The surface-water circulation became more active. The major anticyclonic gyre spread over the Indian Ocean and gave rise to upwelling in the western and eastern peripheries. Smaller circulation system complicated the gyre.

In general, the gradual complication of biogeographic (climatic) zoning and surface-water circulation characterized the Mesozoic history of the Indian Ocean. This evolutionary trend was controlled by extension of the ocean basin and by global climatic fluctuations.

ACKNOWLEDGMENTS

I am grateful to V.G. Kaz'min, I.O. Murdmaa, and A.D. Shcherbinin for their fruitful comments to my results and manuscript. The work was supported by the Russian Foundation for Basic Research, project no. 97-05-65698.

Reviewers I.A. Basov and N.M. Chumakov

REFERENCES

Arthur, M.A., Zachos, J.C., and Jones, D.S., Primary Productivity and the Cretaceous, Tertiary Boundary Event in the Oceans, *Cret. Res.*, 1987, vol. 8, pp. 43–54.

Barrera, E. and Huber, B.T., Evolution of Antarctic Waters during the Maestrichtian: Foraminifer Oxygen and Carbon Isotope Ratios, ODP Leg 113, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1990, vol. 113, pp. 813–823.

Barrera, E., Huber, B.T., Savin, S.M., and Webb, P.-N., Antarctic Marine Temperatures: Late Campanian Through Early Paleocene, *Paleoceanography*, 1987, vol. 2, no. 1, pp. 21–47.

Barron, E.J., Global Cretaceous Paleogeography—International Geologic Correlation Program Project 191, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1987, vol. 59, pp. 207–216.

Baumgartner, P.O., Bown, P., Marcoux, J., *et al.*, Early Cretaceous Biogeographic and Oceanographic Syntheses of Leg 123 (off Northwestern Australia), *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 123, pp. 739–758.

Bralower, T.J. and Siesser, W.G., Cretaceous Calcareous Nannofossil Biostratigraphy of Sites 761, 762, and 763, Exmouth Plateau, Northwest Australia, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 122, pp. 529–556.

Brenner, W., Dinoflagellate Cyst Stratigraphy of the Lower Cretaceous Sequence at Sites 762 and 763, Exmouth Plateau, Northwest Australia, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 122, pp. 511–528.

Bukry, B., Coccolith Stratigraphy, Offshore Western Australia, Deep Sea Drilling Project, Leg 27, *Initial Repts. Deep*

Sea Drill. Project, Washington: US Govern. Print. Office, 1974, vol. 27, pp. 623–630.

Chumakov, N.M., Zharkov, M.A., German, A.B., *et al.*, Climatic Belts of the Mid-Cretaceous Time, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 42–63.

Chumakov, N.M., The Problem of the Warm Biosphere, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 3–14.

Gartner, S., Jr., Johnson, D.A., and McGowran, B., Paleontology Synthesis of Deep Sea Drilling Results from Leg 22 in the Northeastern Indian Ocean, *Initial Repts. Deep Sea Drill. Project*, Washington: US Govern. Print. Office, 1974, vol. 22, pp. 805–814.

Gradstein, F.M., Legs 122 and 123, Northwestern Australian Margin—a Stratigraphic and Paleogeographic Summary, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 123, pp. 801–816.

Herb, R., Cretaceous Planktonic Foraminifera From the Eastern Indian Ocean, *Initial Repts. Deep Sea Drill. Project*, Wasington: US Govern. Print. Office, 1974, vol. 26, pp. 745–769.

Huber, B.T., Maestrichtian Planktonic Foraminifer Biostratigraphy of the Maud Rise (Weddell Sea, Antarctica): ODP Leg 113 Holes 689B and 690C, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1990, vol. 113, pp. 489–513.

Huber, B.T., Maestrichtian Plankton Foraminifer Biostratigraphy and the Cretaceous, *Tertiary Boundary at Hole 738C, Kerguelen Plateau (Southern Indian Ocean), Proc. Ocean. Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1991, vol. 119, pp. 451–466.

Huber, B.T., Hodell, D.A., and Hamilton, C.P., Middle–Late Cretaceous Climate of the Southern High Latitudes: Stable Isotopic Evidence for Minimal Equator-to-Pole Thermal Gradients, *Bull. Geol. Soc. Am.*, 1995, vol. 107, no. 10, pp. 1164–1191.

Huber, B.T. and Watkins, D.K., Biogeography of Campanian–Maastrichtian Calcareous Plankton in the Region of Southern Ocean: Paleogeographic and Paleoclimatic Implication, *The Antarctic Paleoenvironment: A Perspective on Global Change. Amer. Geophys. Union. Antarct. Res. Ser.*, Kennett, J.P. and Warnke, D.A., Eds.,1992, vol. 56, pp. 31–60.

Kaminski, M.A., Gradstein, F.M., and Geroch, S., Uppermost Jurassic to Lower Cretaceous Deepwater Benthic Foraminiferal Assemblages from Site 765 on the Argo Abyssal Plain, *Proc. Ocean. Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 12, pp. 239–269.

Krasheninnikov, V.A., Significance of Oceanic Deposits for Development of the Mesozoic–Cenozoic Stratigraphic Scale (Indian Ocean), *Vopr. Mikropaleontologii*, 1978, no. 19, pp. 124–226.

Krasheninnikov, V.A. and Basov, I.A., *Stratigrafiya mela Yuzhnogo okeana* (Cretaceous Stratigraphy of the Southern Ocean), Moscow: Nauka, 1985.

Levitan, M.A., *Paleookeanologiya Indiiskogo okeana v melu-neogene* (Paleooceanology of the Indian Ocean in the Cretaceous–Neogene), Moscow: Nauka, 1992.

McGowran, B., Foraminifera, *Initial Repts. Deep Sea Drill. Project*, Washington: US Govern. Print. Office, 1974, vol. 2, pp. 609–628.

Nomura, R., Paleoceanography of Upper Maestrichtian to Eocene Benthic Foraminiferal Assemblages at Sites 752, 753, and 754, Eastern Indian Ocean, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 121, pp. 3–30.

Oberhansli, H., Latest Cretaceous–Early Neogene Oxygen and Carbon Isotopic Record at DSDP Sites in the Indian Ocean, *Marine Micropaleontology*, 1986, vol. 10, pp. 95–115.

Pospichal, J.J., Dehn, J., Driscoll, N.W., *et al.*, Cretaceous–Paleogene Biomagnetostratigraphy of Sites 752-755, Broken Ridge: a Synthesis, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 121, pp. 721–741.

Proto Decima, F., Leg 27 Calcareous Nannoplankton, *Initial Repts. Deep Sea Drill. Project*, Washington: US Govern. Print. Office, 1974, vol. 27, pp. 589–621.

Quilty, P., Cenomanian–Turonian and Neogene Sediments From Northeast of Kerguelen Ridge, Indian Ocean, *J. Geol. Soc. Austral.*, 1973, vol. 20, part 3, pp. 361-367.

Quilty, P., Upper Cretaceous Planktonic Foraminifers and Biostratigraphy, Leg 120, Southern Kerguelen Plateau, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992a, vol. 120, part 1, pp. 371–392.

Quilty, P., Upper Cretaceous Benthic Foraminifers and Paleoenvironments, Southern Kerguelen Plateau, Indian Ocean, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992b, vol. 120, part 1, pp. 393–444.

Risawati, P., Upper Cretaceous Calcareous Nannofossils from Broken Ridge and Ninetyeast Ridge, Indian Ocean, *Proc. Ocean Drill. Program, Sci. Res.*, College Station, TX: Ocean Drilling Program, 1992, vol. 121, pp. 141–170.

Royer, J.-Y. and Coffin, M.F., Jurassic to Eocene Plate Tectonic Reconstructions in the Kerguelen Plateau Region, *Proc. Ocean Drill. Program Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 120, part. 2, pp. 917–928.

Scotese, C.R., Jurassic and Cretaceous Plate Tectonic Reconstructions, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1991, vol. 87, nos. 1–4, pp. 493–501.

Scotese, C.R., Royer, J.Y., Mueller, R.D., *et al.*, *Atlas of Mesozoic and Cenozoic Plate Tectonic Reconstructions. Tech. Report 90*, Austin (Texas): Univ. of Texas., Inst. for Geophysics, 1987.

Sigal, J., Comments on Leg 25 Sites in Relation to the Cretaceous and Paleogene Stratigraphy in the Eastern and Southeastern Africa Coast and Madagascar Regional Setting, *Int. Repts. Deep Sea Drill. Project*, Washington: US Govern. Print. Office, 1974, vol. 25, pp. 687–723.

Sliter, W.V., Cretaceous Planktonic Foraminifers From Sites 865, 866, and 869: a Synthesis of Cretaceous Pelagic Sedimentation in the Central Pelagic Ocean Basin, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1995, vol. 143, pp. 15–30.

Stevens, G.R., Southwest Pacific Faunal Palaeobiogeography in Mesozoic and Cenozoic Times: a Review, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1980, vol. 31, pp. 153–196.

Thierstein, H.R., Asaro, F., Ehrmann, W.U., *et al.*, The Cretaceous, Tertiary Boundary at Site 738, Southern Kerguelen Plateau, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1991, vol. 119, pp. 849–868.

Van Eijden, A.J.M. and Smit, J., Eastern Indian Ocean Cretaceous and Paleogene Quantitative Biostratigraphy, *Proc. Ocean. Drill. Program, Sci. Results*, Washington: 1991, vol. 121, pp. 77–124.

Veevers, J.J. and Heirtzler, J.R., Tectonic and Paleogeographic Syntheses of Leg 27, *Initial Repts. Deep Sea Drill. Project*, Washington: US Govern. Print. Office, 1974, vol. 27, pp. 1049–1054.

Watkins, D.K., Upper Cretaceous Nannofossils from Leg 120, Kerguelen Plateau, Southern Ocean, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 120, part 1, pp. 343–370.

Watkins, D.K., Quilty, P.G., Mohr, B.A.R., *et al.*, Paleontology of the Cretaceous of the Central Kerguelen Plateau, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 120, part 2, pp. 951–960.

Wie, W. and Thierstein, H.R., Upper Cretaceous and Cenozoic Calcareous Nannofossils of the Kerguelen Plateau (Southern Indian Ocean) and Prydz Bay (East Antarctica), *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1991, vol. 119, pp. 467–494.

Wonders, A.A.H., Cretaceous Planktonic Foraminiferal Biostratigraphy, Leg 122, Exmouth Plateau, Australia, *Proc. Ocean Drill. Program, Sci. Results*, College Station, TX: Ocean Drilling Program, 1992, vol. 12, pp. 587–599.

Zharkov, M.A., Murdmaa, I.O., and Filatova, N.I., Paleogeography of the Mid-Cretaceous Period, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 15–41.

Zharkov, M.A., Murdmaa, I.O., and Filatova, N.I., Paleogeography of the Berriasian–Barremian Ages of the Early Cretaceous, *Stratigr. Geol. Korrelyatsiya*, 1998, vol. 6, no. 1, pp. 49–72.

Zharkov, M.A., Murdmaa, I.O., and Filatova, N.I., Paleogeography of the Coniacian–Maastrichtian Ages of the Late Cretaceous, *Stratigr. Geol. Korrelyatsiya*, 1998, vol. 6, no. 3, pp. 1–15.

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 470–481. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 52–64.
Original Russian Text Copyright © 2000 by Gorbachik, Kopaevich, Naidin.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

The Albian–Cenomanian Boundary in the Southwestern Crimea

T. N. Gorbachik, L. F. Kopaevich, and D. P. Naidin

Moscow State University, Vorob'evy gory, Moscow, 119899 Russia

Received October 19, 1998

Abstract—Two sections of Albian–Cenomanian boundary beds are studied in the Bakhchisarai area of the southwestern Crimea near the Research–Training Center of the Geological Faculty of the Moscow State University. Ages of lithostratigraphic subdivisions recognized in the sections are substantiated by paleontological data. A hiatus at the Albian–Cenomanian boundary is shown to be insignificant. Distribution of planktonic and some benthic foraminifers in the boundary beds is described for the first time. In terms of micro- and macropaleontological characteristics, the studied beds are well correlative with the new Albian–Cenomanian boundary stratotype (the Mont Risou section located 150 km to the north of Marseilles, Alpes de Haute province of southeastern France) authorized at the Second International Symposium on Cretaceous Stage Boundaries, Brussels, 1995. The ammonite and inoceram faunas coexisting in the Crimean sections enable correlation between fossil assemblages typical of the Tethyan and European paleobiogeographic areas (EPA). After the additional comprehensive study, the sections can be regarded as the eastern standards for the EPA.

Key words: *Albian, Cenomanian, Upper Cretaceous, biostratigraphy, ammonites, inocerams, planktonic and benthic foraminifers, European paleobiogeographic area*

Some time ago, the Subcommission on Cretaceous Stratigraphy of the International Stratigraphic Commission suggested to refine the Cretaceous stage boundaries. In this respect, the Cretaceous carbonate beds widespread in Crimea are of particular interest. These beds are constituents of the upper monoclinal complex in the second range of the Crimean Mountains. Almost everywhere in Crimea, the Cenomanian deposits overlie the upper Albian beds without angular unconformity. In the terminal Early–Late Cretaceous, the Crimea was a part of the European paleobiogeographic area (EPA), and the West European stage and zonal units can be easily recognized in the Crimean succession. The upper Albian–Upper Cretaceous succession in Crimea is unique and very informative, because its structure and some features (hiatuses, levels of anoxic events) reflect the global climatic changes, sea-level oscillations, and sedimentological trends. At the same time, the succession shows a series of intriguing local features.

The Albian–Cenomanian boundary deposits of the Crimean Mountains were recognized by N.I. Karakash (1907) on the basis of paleontological data and described by G.F. Weber with co-authors (Weber *et al.*, 1911; Weber and Malychef, 1923). Later the deposits were studied in the Kacha–Bodrak interfluve eastward of the Bakhchisarai, where the upper Albian *hard* limestones and sandstones are separated from the Cenomanian marls by less hard, locally *soft* green sandstones bearing ammonites of genus *Stoliczkaia* and attributed to the terminal Albian (Naidin *et al.*, 1975). At that time, the *Pervinquieria inflata* (al_3^2), *Stoliczkaia dispar* (al_3^3), and *Mantelliceras mantelli* (cm_1) zones were established in the boundary interval (Marcinowski and Naidin, 1976). According to published data, lithological and paleontological characteristics of these units are as follows.

al_3^2 (Baraboshkin, 1997, p. 28; Yanin, 1997, p. 34; Yanin and Vishnevskii, 1989, pp. 115–123; Marcinowski and Naidin, 1976, p. 88, Figs. 2, 3, 5, Plates 1, 2, 4).

Locally highly calcareous nodular (structural features of secondary cementation) sandstones and clastic[1] limestones represent the lower part of the Sel'bukhra Formation lying transgressively, with angular unconformity, on deposits different in age. The formation was recognized by B.T. Yanin (1997, p. 34). In the south of the Kacha–Bodrak interfluve, the deposits are very hard, forming cliffs. In the Kacha River section, where the unit is 20 m thick, its deposits rest on the basal bed of pebbly conglomerate. Northward, along the distance of 13 km, the unit is wedging out in the Bodrak River valley.

[1] Clasts are represented by quartz, feldspars, quartzite, and effusive rocks, and also by remains of different calcareous organisms: red algae including *Archaeolithothamnium rude* Lemoine (identification of K.B. Korde), serpulids, echinoderms, bryozoans, brachiopods, and bivalves. Tests of multichamber planktonic foraminifers occur sporadically. The size range of echinoderm and algae remains is 0.5–1.5 mm, and that of other fossils is 0.05–0.3 mm. The rock and mineral clasts are weakly rounded or angular. In the rock, there are present glauconite grains of different genesis. The matrix is calcitic.

Small spiral serpulids, among which *Rotularia damesii* (Noetling) (identification of S.I. Pasternak) is most common, represent a distinctive feature of the unit. Accordingly, Karakash (1907) described the unit as "Serpulid Beds." The coexisting ammonites are represented by *Mortoniceras (Mortoniceras) rostratum* (Sowerby), *M. (M.) perinflatum* (Spath), and other representatives of this genus, as well as by large *Puzosia* forms. Most frequent among bivalves are *Aucellina gryphaeoides* (Sowerby), *Amphidonte arduennsis* (d'Orbigny) known in Russia as *Gryphaea arduennensis* (d'Orbigny) (Malchus, 1990), and *Plicatula inflata* Sowerby. Poorly preserved echinoid species *Holaster laevis* de Luc occur sporadically.

al_3^3 (Naidin and Alekseev, 1980, Fig. 3, Plate 1, 1981, Figs. 1 and 3; Naidin *et al.*, 1975, Fig. 1; Marcinowski and Naidin, 1976, p. 91, Figs. 3, 5, and 6, Plates 1, 2, and 4; Naidin, 1981, pp. 35–39, Fig. 6 and 7, Plate 5).

The unit up to 2 m thick is composed of glauconite-bearing sandstones with variable greenish tints. If the rock varieties are relatively hard, they are usually placed in the al_3^2 interval (Naidin and Alekseev, 1980, Fig. 2, stratigraphic column 8) in contrast to soft sandstones of the lowermost Cenomanian (Naidin and Alekseev, 1980, Fig. 2, stratigraphic sections 9 and 10). The thorough examination of "the green sandstones" shows that their terrigenous components are represented by grains of quartz, less frequent quartzite, orthoclase, magnetite, garnet, and pyroclastic material (angular fragments of plagioclases and amphiboles cemented by carbonate-clayey matter) varying in abundance along the strike and upward in the section. Indistinctly bedded sandstones locally include abundant gravel-sized quartz grains and rare fine pebbles of smoky quartz.

The contact of sandstones with the **al_3^2** beds is sharp, showing signs of erosion (Fig. 2; Naidin and Alekseev, 1980, Figs. 2 and 3; 1981, Fig. 3). The upper contact with Cenomanian deposits is less distinct, because the basal beds of the latter (Member I) are represented in some sections by glauconite-bearing sandstones similar in appearance to the **al_3^3** sandstones and were previously referred to that unit (Naidin and Alekseev, 1981, Fig. 3). However, the **al_3^3** sandstones are closer related to **cm_1** than to al_3^3. They either grade into Member I, or are separated from it by a minor hiatus (Matrenitskii, 1968). In the Kacha–Bodrak interfluve, "the al_3^3 green sandstones" are most fully represented near the Mt. Kremennaya, being absent in some sections near the Prokhladnoe Village and to the south of the Mt. Sel'bukhra.

Rare ammonites of the unit are represented by poorly preserved *Stoliczkaia notha* (Seeley), *Mariella* cf. *lewesiensis* (Spath), and *Lechites* cf. *gaudini* (Pictet et Campiche). Incompletely preserved small *Neohibolites* rostra occur sporadically. Rostra presumably corresponding to *Parahibolites tourtiae* (Weigner) were found in these deposits at Exposure 9 of the Mt. Kremennaya site (Naidin and Alekseev, 1980, Fig. 2).

In addition, the unit yields scarce specimens of *Inoceramus anglicus* Woods and more frequent casts and valves of *Aucellina gryphaeoides* (Sowerby), *Gryphaeostrea canaliculata* (Sowerby), and other pelecypods. Some brachiopod forms and serpulids *Glomerula gordialis* (Schlotheim) also present here.

cm_1, Member I (Naidin and Alekseev, 1980, Fig. 3, Plate 1; 1981, p. 8, Fig. 1; Naidin *et al.*, 1975, Fig. 1; Naidin, 1981, pp. 39–46, Fig. 7, Plate 5).

The member is composed of fissured flaggy marls of varying green color, the lower beds of which are glauconite-bearing and heavily arenaceous. Sporadic tests and imprints of *Puzosia planulata* (Sowerby) and *Mantelliceras* sp. indet. appear for the first time at the base of this marly member. Characteristic accumulations of of *Neohibolites menjailenkoi* Gustomesov *rostra*[2] represent "the first belemnite level" (Alekseev and Naidin, 1970). Remains of *Inoceramus crippsi crippsi* Mantell are confined to the base of the member. Upward in the section, this form coexists with *I. crippsi hoppenstedtensis* Troger and *I. virgatus* Schluter (Naidin *et al.*, 1975). Distribution of the Albian and Cenomanian deposits in the southwestern Crimea is shown in Fig. 1.

REMARKS CONCERNING THE MONT RISOU SECTION OF THE ALBIAL–CENOMANIAN BOUNDARY STRATOTYPE

The universally accepted "standard scales" and, correspondingly, stage boundaries between two series of the Cretaceous System are based on distribution of ammonites. The "ammonite standard" of the Albian–Cenomanian boundary has been considered in a series of publications by C.W. Wright, W.J. Kennedy, J.M. Hancock, F. Amedro, F. Robaszynski and other West European researchers. None of other macrofossil groups has been discussed at two last international conference on the Cretaceous stage boundaries (Birkelund *et al.*, 1984; Tröger *et al.*, 1996; *Proceedings...*, 1996).

Thus, one can see that the preference is given to fauna of the Tethyan paleobiogeographic affinity. Hence, the Cretaceous correlation trends are oriented from the Tethys to the northern extensive regions of Cretaceous deposits. However, the Tethyan ammonites are useless, when we think of the direct correlation all over the last enormous territory. Meanwhile, it is known well that another group of Cretaceous (particularly, Albian–Cenomanian) macrofossils, namely, inoceramus are of a high correlative value (Sornay, 1981; Tröger, 1981, 1996; Kaplan *et al.*, 1984; and others).

[2] This species differs from *Neohibolites ultimus* (d'Orbigny) (Naidin *et al.*, 1975) and is known as well from the lower Cenomanian deposits of northern Bulgaria (Iolkichev *et al.*, 1988).

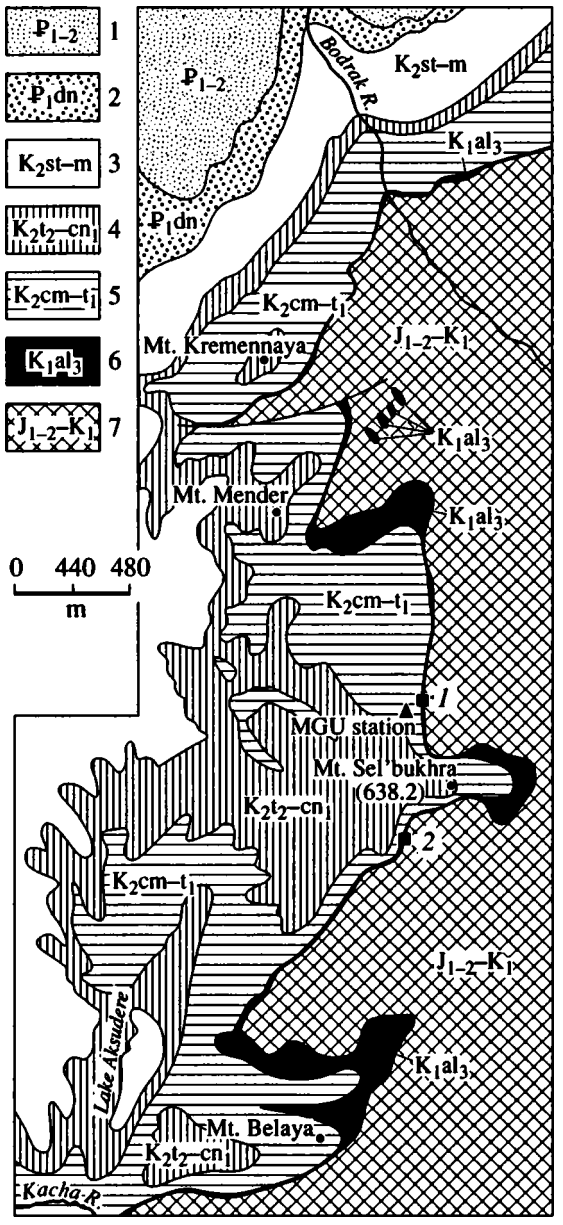


Fig. 1. Schematic geological map of the Kacha–Bodrak interfluve: (1) P_{1-2}, Paleocene (Thanetian)–Eocene; (2) P_1dn, Danian; (3) K_2st-m, Santonian–Campanian–Maastrichtian; (4) $K_2t_2-cn_1$, upper Turonian–lower Coniacian; (5) K_2cm-t_1, Cenomanian–lower Turonian; (6) K_1al_3, upper Albian (al_2^{2-3}); (7) $J_{1-2}-K_1$, pre-upper Albian deposits, including al_3^1. Study sites: (*1*) Moscow University Training Center; (2) Koyas-Dzhilga Ravine.

The Mont Risou section that is located 150 km to the north of Marseilles in Alpes de Haute province of southeastern France was proposed as the Albian–Cenomanian boundary stratotype at the Second International Symposium on the Cretaceous Stage Boundaries. It has a great advantage being characterized by both inocerams and ammonites (Gale *et al.*, 1996). The Mont Risou section contains species *Inoceramus anglicus* Woods and *I. crippsi* Mantell characteristic of the Crimean sections. It is also remarkable that these and other species similar in stratigraphic position were also described from the paleobiogeographic realms situated many thousand kilometers away from the sections of France and Crimea. For instance, *I. anglicus* Woods, *I.* ex gr. *concentricus* Parkinson, and *I. crippsi* Mantell were reported from Greenland (Maync, 1952; Donovan, 1957). In the inoceram-based stratigraphic scheme for the Cretaceous of eastern Russia (Zonova, 1992, Table 8), the boundary between the Albian and Cenomanian stages is coincident with that between the *Inoceramus anglicus* and *Inoceramus* aff. *crippsi* zones!

According to published information, the vertical ranges of ammonites, inocerams, planktonic foraminifers and nannofossils are perfectly studied in the Mont Risou section. We think that it can be accepted as a global reference section or the Albian–Cenomanian boundary stratotype, because the authors of the proposal are not inclined to overestimate the correlative value of "the ammonite standard."

However, we cannot agree with their suggestion to draw the Cenomanian lower boundary using the biostratigraphic marker only and placing it at the first occurrence level of *Rotalipora globotruncanoides* (Brotzen). Our reasons are discussed in the following section of the article.

HISTORY OF IDEAS TO DETECT THE ALBIAN–CENOMANIAN BOUNDARY BASED ON PLANKTONIC FORAMINIFERS

The Albian–Cenomanian boundary established in the ammonite scale was also studied by experts in micropaleontology, who analyzed distribution of foraminifers across it. This was important, because the Cretaceous biostratigraphic zonation in warm-water basins is based on the distribution patterns of planktonic foraminifers.

In one of the earliest Cretaceous zonation suggested by Bolli (1966), who studied distribution of foraminifer in sedimentary sequences of the Trinidad Island (Bolli, 1959), the Albian–Cenomanian boundary coincides with the boundary between the *Rotalipora ticinensis ticinensis* and *R. appenninica appenninica* zones.

After study of the Lower Cretaceous deposits in the Vocontienne depression (southeastern France), Moullade (1966) considered the *Rotalipora appenninica–Schackoina bicornis* Zone as the uppermost in the Albian Stage and corresponding to the ammonite *Stoliczkaia dispar* Zone. Later Moullade (1974) suggested the Mediterranean Cretaceous zonation, where the Vraconian Substage comprising the foraminiferal *Planomalina buxtorfi* and *Schackoina molinensis* zones represents the upper Albian subdivision, and the Albian–Cenomanian boundary is placed at the base of the *Rotalipora brotzeni* Zone.

In the Mediterranean Cretaceous zonation suggested by Sigal (1977), the Vraconian Substage corresponds to the *Rotalipora appenninica–Planomalina buxtorfi* Zone, and the lower Cenomanian *Rotalipora globotruncanoides–R. brotzeni* Zone is correlated with the ammonite *Mantelliceras mantelli* Zone.

Sigal (1948) initially described zonal species *Rotalipora globotruncanoides* and *R. brotzeni* as representing different genera: the former was referred to the genus *Rotalipora*, and the latter was classed with the type species of new genus *Thalmanninella*. Sigal noted the following main distinctions between these species: (1) *globotruncanoides* tests have 5–7 chambers in contrast to 7–9 chambers of *brotzeni* forms; and (2) *globotruncanoides* tests are larger in size and less convex, whereas additional sutural apertures of *brotzeni* forms are situated nearer to the umbilicus, and their chambers in the umbilical side the are so closely arranged that septal sutures are not deepened. These distinctions allowed Sigal to establish the new genus *Thalmanninella*. However, both generic and specific characters of both taxa are indistinct, and later Sigal (1977) referred the type species *Thalmanninella brotzeni* to the genus *Rotalipora*. The systematic position of the genus *Thalmanninella* is disputable: some authors consider it as independent taxon, while the others class with the *Rotalipora* subgenus, or with a species of this genus. We support the last opinion.

In the Crimea and Caucasus, none of the Albian–Cenomanian sections is monotonous in lithology and displaying regular distribution of planktonic foraminiferal assemblages. In the Crimean sections with minimal hiatuses, the successive changes in planktonic foraminiferal species are the same as in the Mediterranean sections, and the Albian–Cenomanian boundary is usually placed here between the *Rotalipora ticinensis* and *R. appenninica* zones (Gorbachik and Krechmar, 1969; Maslakova, 1978; Gorbachik, 1986). *Rotalipora ticinensis* occurs sporadically, while *R. appenninica* is abundant. Other experts on the Cretaceous stratigraphy in Crimea reported on foraminiferal assemblages with *Rotalipora* aff. *appenninica* (Renz) and *Thalmanninella brotzeni* Sigal from the upper Albian deposits of the northern and northwestern parts of the peninsula (the drilling data) (Bogaets *et al.*, 1980). Plotnikova (1982), who summarized drilling data on the Crimean Plain and investigated outcrops in the southwestern part of the Crimean Mountains, suggested the upper Albian zonation based on distribution of planktonic foraminifers. She recognized the following local units (from the base upward): (1) *Ticinella* (?) aff. *breggiensis*, (2) *Globigerinelloides ultramicrus*, (3) *Praeglobotruncana delrioensis*, and (4) *Rotalipora ticinensis–R. appenninica* Beds. Units 3 and 4 are correlative with the *Stoliczkaia* Beds. "The Albian–Cenomanian boundary is defined at the last occurrence level of Albian forms, mainly of some nodosariids, which simultaneously corresponds to the first occurrence level of *Rotalipora brotzeni* (Sigal)" (Plotnikova, 1982, p. 137). Regretfully, descriptions and pictures of species are missing from two last publications, and controversial understanding of taxa may lead away from an objective inference.

TAXONOMY AND STRATIGRAPHIC RANGES OF FORAMINIFERS IN THE STUDED SECTIONS

Bearing in mind problems concerning the Albian–Cenomanian boundary, Naidin collected seven samples from two outcrops near the Prokhladnoe Village of the southwestern Crimea: one located in the Koyas-Dzhilga Ravine, and another near the Research-Training Center of the Moscow University (Fig. 2). The samples characterize the Albian sandstones and Cenomanian sandstones and marls. Three samples yielded only unidentifiable fragments of agglutinated foraminiferal tests, while the others produced abundant tests of planktonic foraminifers and less numerous specimens of benthic forms. Last samples allowed us to determine the taxonomic composition of foraminifers, to correlate the sampled sections, and to estimate age of host deposits.

Sand and sandstone samples yielded from few specimens (Bed 4, the Koyas-Dzhilga site) to several dozens of foraminiferal tests (Bed 2, the site of the University Training Center). At the last site, the higher and most productive Bed 3 yielded dozens of benthic and hundreds of planktonic foraminiferal tests. Less abundant fauna of the same composition was found in the marly Bed 5 of the Koyas-Dzhilga section (Fig. 2).

Among benthic foraminifers, there are two groups of agglutinated and secretory calcareous forms. The first group represents genera *Marssonella* and *Arenobulimina*, whose species are scarce in marl samples, but more abundant (dozens of *Marssonella* specimens) in sandstone and sandy marl samples. Secretory benthic foraminifers (from 1 to 15–20 specimens per sample) belong to genera *Lenticulina, Lingulogavelinella*, and *Pleurostomella*. In all samples, the major part of assemblages consists of planktonic foraminifers. Their single forms lacking keel represent the poorly preserved *Hedbergella* species. Among carinate forms, there are abundant (up to hundreds of specimens) representatives of the genus *Rotalipora* and less abundant *Praeglobotruncana* forms. In total, six benthic and eight planktonic taxa have been identified.

The preservation state of tests is variable. Agglutinated forms are best preserved. Some planktonic foraminifers have deformed tests and partly dissolved walls. Umbilical areas and apertures are filled with rock material. Despite the poor preservation, the wall porosity of many specimens is well observable under electronic and simple microscopes (Plate III, Fig. 7). At the high magnification, different crystalline elements of the walls can be distinguished (Plate III, Figs. 7a and 7b).

A fairly diverse foraminiferal assemblage was identified in the sandstone Bed 2 at the site near the University Training Center (Fig. 2). The assemblage consists

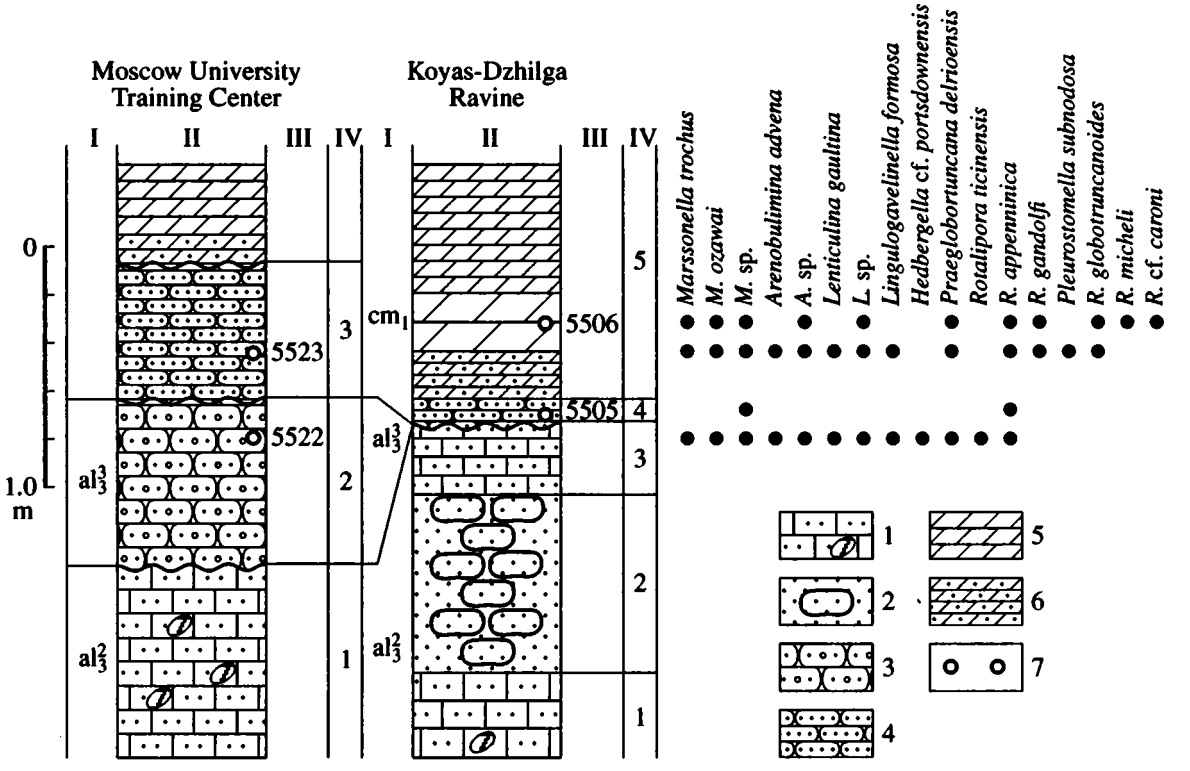


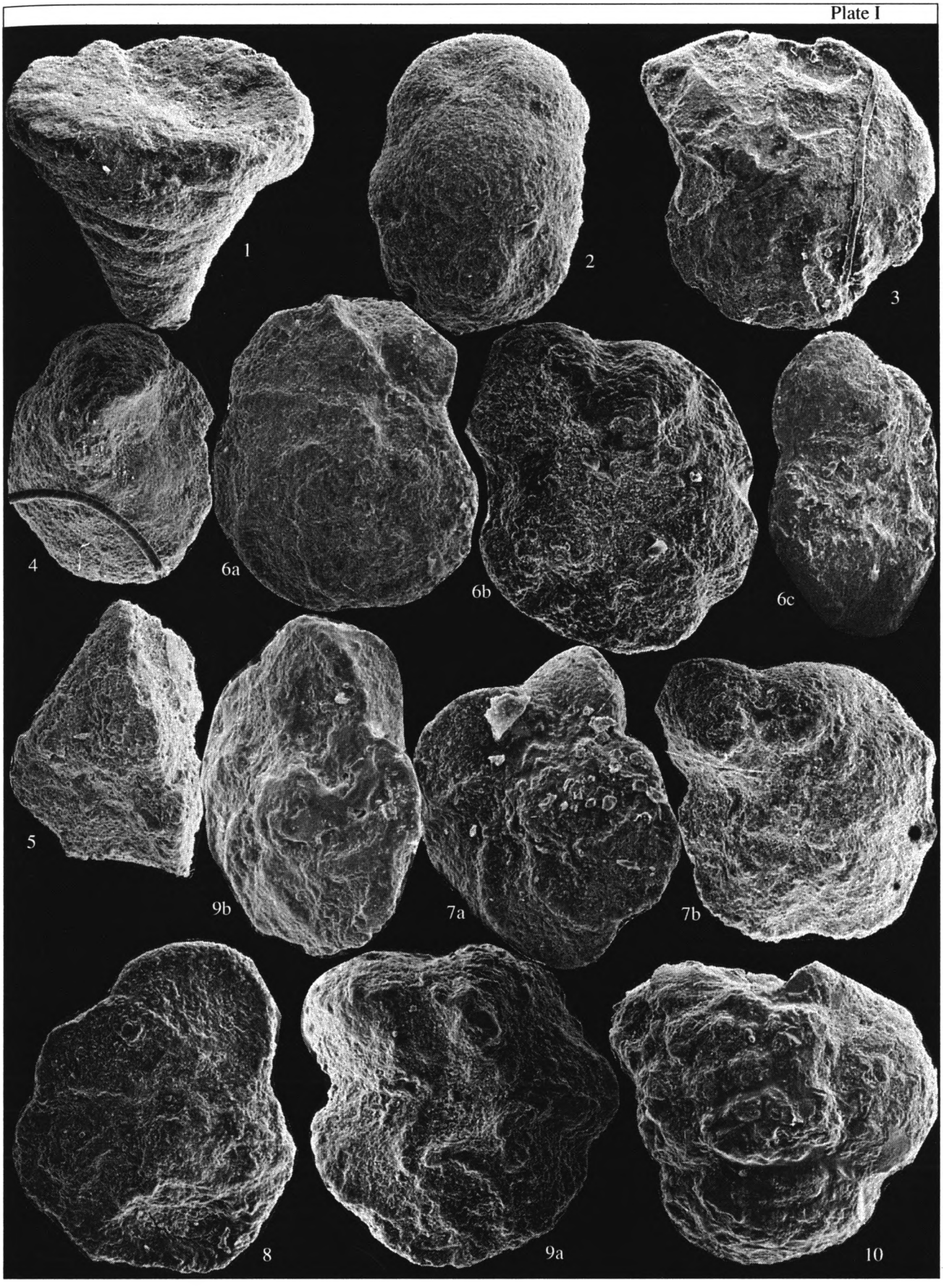
Fig. 2. Foraminiferal distribution in the Albian-Cenomanian boundary deposits of the Moscow University field station and Koyas-Dzhilga Ravine sections: (I) Index; (II) Lithology; (III) Sample numbers; (IV) bed numbers; (1) light gray, locally yellowish or greenish, hard ("crystalline") nodular–clastic sandy limestones bearing glauconite grains; (2) green glauconite-bearing sandstones with gravely inclusions of quartz and dark minerals (presumably a lenticular intercalation in light gray limestone); (3) yellowish green glauconite-bearing sandstones enclosing black (volcanogenic) mineral clasts, abundant quartz grains with "green cover", and small (up to 8 mm) pebbles of smoky quartz; (4) yellowish green (stained yellowish brown when weathered) fine-grained "dusty" sandstone bed bearing glauconite, rare gravely grains of quartz, and marked by fucoids at the top; (5) gray to light gray fissured flaggy marl sandy and glauconite-bearing at the base; (6) sandy glauconite-bearing marl; (7) sampling sites. Section near the Moscow University Training Center was described by Naidin and Alekseev (1980, Fig. 2, stratigraphic section 6; 1981, Fig. 3), and also by Marcinowski and Naidin (1976, Fig. 3). Section of the Koyas-Dzhilga Ravine is located near another one described by Naidin and Alekseev (1980, Fig. 2, stratigraphic section 3).

of the following species: benthic agglutinated *Arenobulimina advena* (Cushman), *A.* sp., *Marssonella trochus* (d'Orbigny), and *M. ozawai* Chapman; secretory benthic *Lenticulina gaultina* (Berthelin), *L.* sp., and *Lingulogavelinella jarzevae* (Vassilenko); planktonic *Hedbergella* cf. *portsdownensis* (Williams-Mitchell), *Praeglobotruncana delrioensis* (Plummer), *Rotalipora appenninica* (Renz), and *R. ticinensis* (Gandolfi). The listed forms are known from the upper Albian and Cenomanian deposits of different Tethyan and Boreal regions. For instance, *Lingulogavelinella formosa* (Brotzen) (Plate I, Figs. 4, 5) has been first described by Brotzen (1945) from the "Holviken" Formation of the upper Albian–Cenomanian. Vasilenko (1954) described this species as belonging to the genus *Cibicides* and reported on its wide distribution in the Cenomanian of Moldavia, Donbass, Voronezh uplift, and Mangyshlak. Kaptarenko-Chernousova *et al.* (1979) mentioned its occurrence in the lower Cenomanian of the Baltic region and in the Albian and Cenomanian deposits of Poland. Hart *et al.* (1990) considered the species as characteristic of the upper Albian (the *Stoliczkaia dispar* Zone) and the lower Cenomanian (the *Mantelliceras mantelli* Zone) of southeastern England.

Marssonella trochus (d'Orbigny) (Plate I, Fig. 1) is a species of the wide geographic and stratigraphic ranges, and, similarly to *Marssonella ozawai* Cushman from our collection, it is known from the Albian–Cenomanian boundary deposits of southeastern England (Hart *et al.*, 1990). According to Frieg (1979), *Arenobulimina advena* Cushman (Plate I, Fig. 2) has distribution range from the upper Albian *S. dispar* Zone to the Campanian, and *Lenticulina gaultina* (Berthelin) (Plate I, Fig. 3) is widespread in the Albian deposits of different regions. Thus, the benthic foraminifer assemblage of Bed 2 indicates the late Albian–early Cenomanian age of the host deposits.

The planktonic group of the same bed is mainly represented by keeled forms. Single tests lacking keel are identified as *Hedbergella* cf. *portsdownensis* (Williams-Mitchell) (Plate I, Fig. 10) known from the upper Albian–Cenomanian of the Crimea (Gorbachik, 1986)

Plate I



and from the Cenomanian of Europe, North Africa, and the United States (Maslakova, 1978). Dominant keeled forms are the relatively small *Praeglobotruncana delrioensis* (Plummer) having a narrow umbilicus and lacking additional apertures; they are widespread almost world-wide in the upper Albian–Cenomanian deposits. Tests of *Rotalipora ticinensis* (Gandolfi) (Plate I, Figs. 6, 7) are less abundant. They are relatively large in size and have broad umbilicus with additional apertures located inside. *Rotalipora ticinensis* (Gandolfi) is the index-species of the upper Albian zone in the scheme of Robaszynski and Caron (1995). Bed 2 contains single tests of *Rotalipora appenninica* (Renz) (Plate I, Figs. 8, 9), the index-species of the uppermost Albian zone. In many Tethyan areas, this species appears at the top of the Albian ranging up to the terminal lower Cenomanian and even to the basal middle Cenomanian. Robaszynski and Caron (1979) consider it as characteristic of the uppermost Albian *Rotalipora appenninica* Zone. In their publication of 1995, these authors attributed this zone to the Vraconian Substage. Analyzing data on the Crimean sections, we arrived at the following conclusion: either the Bed 2 corresponds to the *Rotalipora appenninica* Zone, or it represents a condensed horizon containing foraminiferal tests of the both *Rotalipora ticinensis* and *Rotalipora appenninica* zones. The first supposition seems more probable.

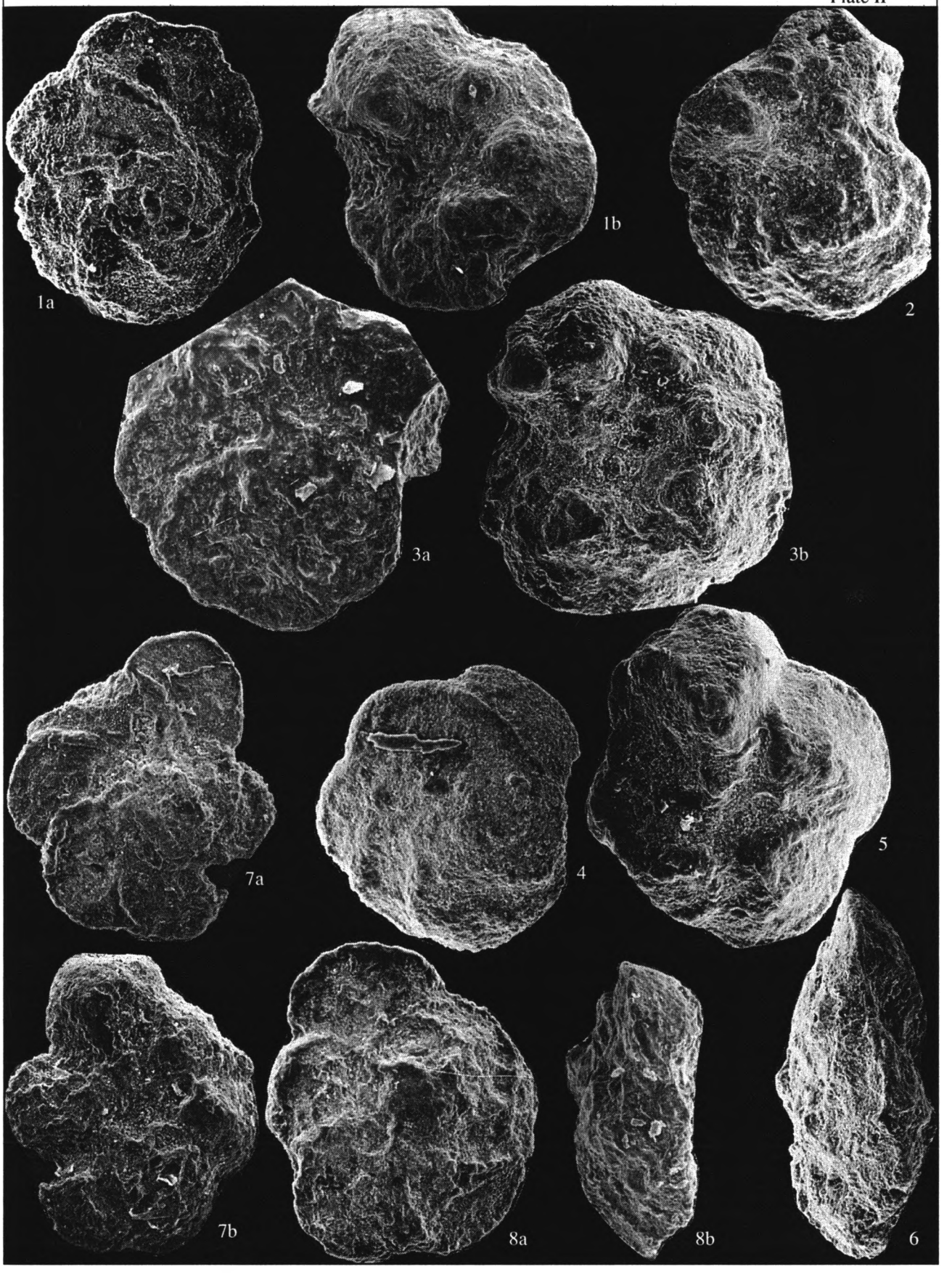
Bed 3 of the same outcrop yields more abundant and diverse fauna. All species of benthic foraminifers listed above were found at this level. A single test of *Pleurostomella subnodosa* Reuss widespread in the Albian–Cenomanian deposits (*Atlas...*, 1960) was also discovered. The bed is especially rich in tests of keeled planktonic foraminifers; we counted few hundreds of their specimens. Similarly to the underlying bed, Bed 3 contains *Praeglobotruncana delrioensis* (Plummer), abundant *Rotalipora appenninica* (Renz) and allied forms (Plate II, Fig. 1), single *R. gandolfii* Luterbacher et Premoli Silva showing well-developed sutural apertures (Plate II, Fig. 2), and *R. globotruncanoides* Sigal (Plate II, Fig. 3). The last two species indicate the early Cenomanian age of Bed 3 corresponding either to the *Rotalipora brotzeni* Zone or to the *Rotalipora globotruncanoides* Zone of foraminiferal zonations suggested by Robaszynski and Caron in 1979 and 1995, respectively. We assume that Bed 3 corresponds to the lowermost Cenomanian owing to sporadic occurrence of tests with well-developed sutural apertures.

In the Koyas-Dzhilga section, foraminiferal tests were detected only in Beds 4 and 5. Occurrence of two tests of *Rotalipora appenninica* (Renz) (Plate II, Figs. 4–6) suggests that the sandstone Bed 4 corresponds to the upper Albian *Rotalipora appenninica* Zone. Marly Bed 5 yielded scarce tests of benthic foraminifers (*Marssonella trochus* (d'Orbigny), *Lenticulina* sp., and *Arenobulimina* sp.) and more than 100 specimens of carinate planktonic forms, such as abundant *Praeglobotruncana delrioensis* (Plummer) and *Rotalipora appenninica* (Renz), less frequent *R. gandolfii* Luterbacher et Premoli Silva (Plate II, Figs. 7, 8; Plate III, Fig. 3), single *R. globotruncanoides* Sigal (Plate III, Figs. 1, 2), *R. micheli* (Sacal et Debourle) (Plate III, Figs. 4–6), and *R.* cf. *caroni* Ion (Plate III, Fig. 7). Two latter are known from the lower Cenomanian of the Mediterranean region (Robaszynski and Caron, 1979; Robaszynski *et al.*, 1993). Coexistence of these two taxa with the index-species *Rotalipora globotruncanoides* and *R. gandolfii* in the Bed 5 allows us to correlate this bed with the lower Cenomanian *R. globotruncanoides* Zone (an analog of the *R. brotzeni* Zone). The Bed 5 of the Koyas-Dzhilga section may correspond to a younger level of the lower Cenomanian than the Bed 3 at the site of the University Training Center. This follows from the fact that the lower Cenomanian marls of the Koyas-Dzhilga section contain abundant *Rotalipora* forms with well-developed sutural apertures suggesting a higher evolutionary level of these forms.

The modern concept of the Albian–Cenomanian boundary is presented in the resolutions of the Second International Symposium on the Cretaceous Stage Boundaries (*Proceedings...*, 1996). As stated at the symposium, the main biostratigraphic event marking the Albian–Cenomanian boundary is the first occurrence of single specimens of *Rotalipora globotruncanoides* (Sigal) that was previously suggested by Sigal (1948). Analyzing the Mont Risou section (southern France) proposed for the new Albian–Cenomanian boundary stratotype, Gale *et al.* (1996) distinguished the following bioevents characterizing the corresponding 121-m-thick interval of the sequence: (1) disappearance of formerly abundant *Planomalina buxtorfi* from the lower part of the *Arrhaphoceras (Praeshloenbachia) briacensis* Subzone of the *S. dispar* Zone; (2) speciation of the genus *Rotalipora*, whose representatives *R. ticinensis* and *R. appenninica* range up to the upper part of the ammonite subzone mentioned above;

Plate I. Foraminifers from upper Albian deposits of southwestern Crimea: (1) *Marssonella trochus* (d'Orbigny), specimen no. 282-1, ×60; (2) *Arenobulimina advena* (Cushman), specimen no. 282-2, ×60; (3) *Lenticulina gaultina* (Berthelin), specimen no. 282-3, ×60; (4) *Linguligavelinella jarzevae* (Vassilenko), specimen no. 282-4, umbilical side, ×90; (5) *Linguligavelinella jarzevae* (Vassilenko), specimen no. 282-5, peripheral side, ×90; (6) *Rotalipora ticinensis* (Gandolfi), specimen no. 282-6, spiral (6a), umbilical (6b), and peripheral sides (6c), ×120; (7) *Rotalipora ticinensis* (Gandolfi), specimen no. 282-7, spiral (7a) and umbilical (7b) sides, ×120; (8) *Rotalipora appenninica* (Renz), specimen no. 282-8, spiral side; (9) specimen no. 282-9, umbilical (9a) and peripheral (9b) sides, ×120; (10) *Hedbergella* cf. *portsdownensis* (Williams-Mitchell), specimen no. 282-10, spiral side, ×120. All specimens are from Bed 2 (Sample 5522) of the upper Albian succession near the University Training Center. These and other species pictured in Plates II and III are stored at the Moscow State University, Collection no. 282. at the Chair of Paleontology.

Plate II



(3) simultaneous appearance of *R. gandolfii* and *R. tehamaensis* in the uppermost beds of the subzone; (4) the first occurrence of single *R. globotruncanoides* within the same ammonite zone and the last occurrence of *R. ticinensis* at the same level accepted for the Albian–Cenomanian boundary (Gale *et al.*, 1996); (5) frequent occurrence of *R. globotruncanoides*. The considered level coincides with the first occurrence of ammonite species *Mantelliceras mantelli* and, hence, with the Albian–Cenomanian boundary in traditional interpretation (Birkelund *et al.*, 1984).

The Crimean sections were sampled only near the Albian–Cenomanian boundary, and the data obtained depict only events across this boundary. However, the Mont Risou and Crimean sections show other levels, where planktonic foraminifers mark comparable events (*Proceedings...*, 1996). For instance, Sample 5522 from the site of the University Training Center yielded species *R. ticinensis* (Gandolfi) and *R. appenninica* (Renz), whose stratigraphic range in the Mont Risou section is confined to the upper part of the *Arrhaphoceras (Praeshloenbachia) briacensis* Subzone, the upper one in the ammonite *Stoliczkaia dispar* Zone. Sample 5505 taken somewhat higher from the Koyas-Dzhilga section also marks the coexistence level of *Rotalipora ticinensis* and *R. appenninica* (level 2 of the Mont Risou section). Finally, samples 5523 and 5506 containing *Rotalipora globotruncanoides* are barren of *R. ticinensis*. Thus, the particular levels of Crimean sections correspond to the second, fourth (Sample 5523), and fifth (Sample 5506 with "advanced" *Rotalipora* forms described above) events recorded in the Mont Risou section. The level of the third event is unknown in the Crimea.

Thus, the first occurrence level of *Rotalipora globotruncanoides* Sigal also marks the Albian–Cenomanian boundary in the study area. However, it should be noted that this species, whose first occurrence is suggested to be *the main marker* of the boundary, is hardly distinguishable from close species occurring in older and younger deposits. For instance, Robaszynski *et al.* (1994, p. 434) presented the list of revised taxa and their identifications of 1979. Except for certain species, e.g., *Rotalipora appenninica* identically classified recently and many years ago, there are others in the list, whose taxonomic position was considerably changed. For example, some specimens of *Rotalipora greenhornensis* (1979) and species *R. brotzeni* (1979) were identified in 1994 as *Rotalipora globotruncanoides*. Taking into account the indistinct morphological features of the species under consideration, we doubt that it can be the only leading species for positioning the boundary between stages and, what is more important, between two series of the Cretaceous System. In our opinion, other micropaleontological data, which appeared to be very helpful earlier, must be used.

GENERAL ASSESSMENT OF THE STUDIED ALBIAN–CENOMANIAN BOUNDARY SECTION: RESULTS AND PERSPECTIVES

(1) The boundary is traceable in many easily accessible sections in the Kacha–Bodrak interfluve area. The sections need to be comprehensively studied before selecting one of them as the regional stratotype.

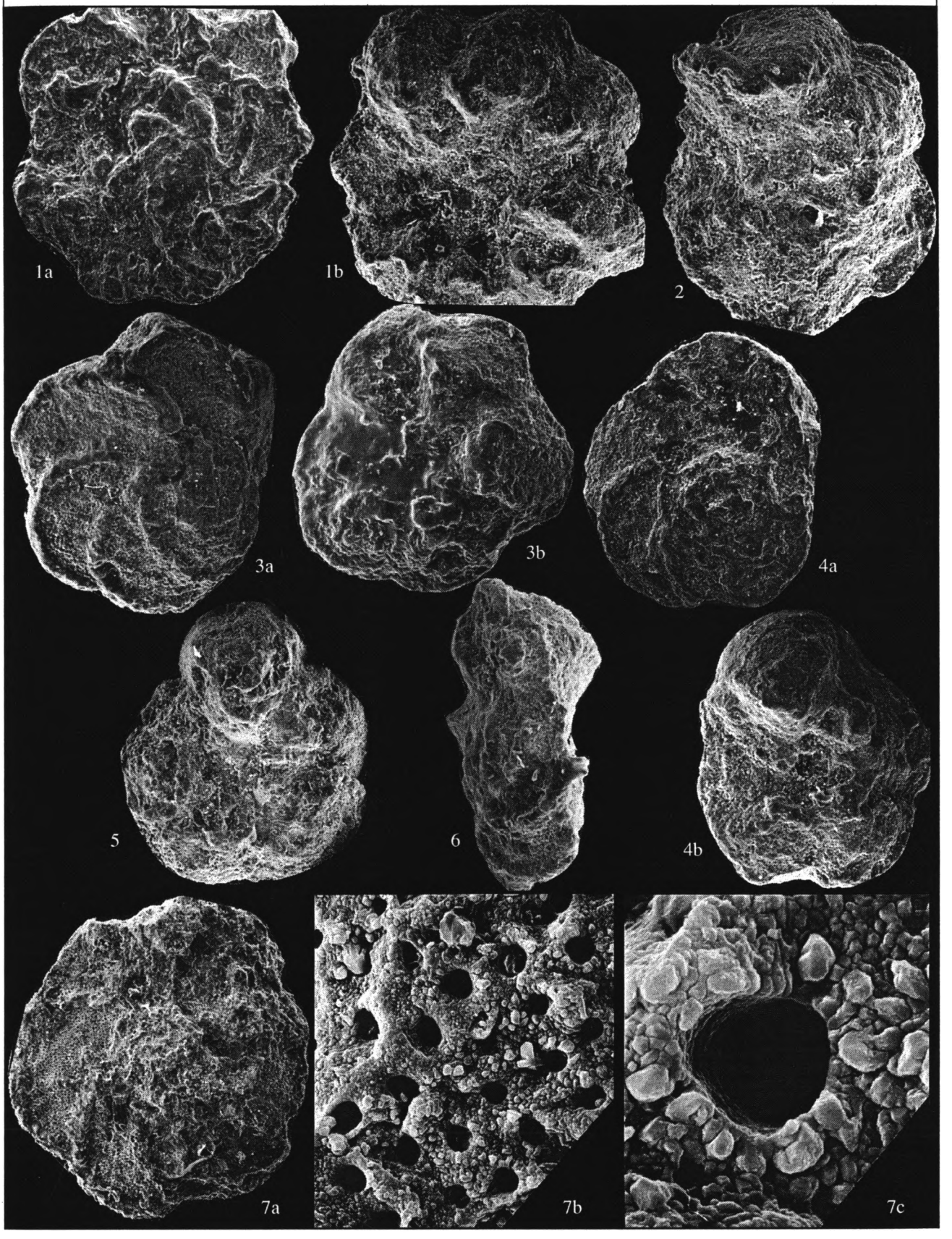
(2) In the southwestern Crimea, the Albian–Cenomanian boundary is detected in the natural succession of beds, which begins with transgressive al_3^2 sediments deposited in extremely shallow environments and replaced upward first by green al_3^3 sandstones accumulated in deeper settings, and then by deep-water marly beds of cm_1. We believe that the term succession is very appropriate here, because the inner hiatuses are very insignificant.

(3) The Albian–Cenomanian deposits of the Kacha–Bodrak interfluve (and of the Crimean Mountains in general) accumulated in the southern zone of the European paleobiogeographic realm (Naidin, 1969), very close to the Tethyan realm, and this gave rise to coexistence of faunas of different paleobiogeographic affinity within the zone.

(4) The paleobiogeographic position of the sections determined the composition of the leading ammonite, belemnite, and inoceram faunas. Regretfully, the ammonite casts are rare and poorly preserved. We should continue the bed-by-bed search for ammonites and other fossils of stratigraphic importance. Our main attention should be paid to "the green sandstones of al_3^3." Stratigraphic ranges of specimens collected should be precisely determined. This particularly concerns the specimens of *Parahibolites tourtiae* found in the Mt. Kremennaya section and in the Albian–Cenomanian boundary beds of the Al'ma River section. This species is known in the Westphalia (Germany), Poland,

Plate II. Foraminifers from Albian–Cenomanian boundary beds of the southwestern Crimea: (1) a form intermediate between *Rotalipora appenninica* (Renz) and *R. gandolfii* Luterbacher et Premoli Silva, specimen no. 282-11, dorsal (1a) and umbilical (1b) sides, ×100; (2) *Rotalipora gandolfii* Luterbacher et Premoli Silva, specimen no. 282-12, spiral side, ×100; (3) *Rotalipora globotruncanoides* Sigal, specimen no. 282-13, (3a) spiral side; (3b) umbilical side; ×90; (4) *Rotalipora appenninica* (Renz), specimen no. 282-14, spiral side; (5) *Rotalipora ticinensis* (Gandolfi), specimen no. 282-15, umbilical side, ×100; (6) *Rotalipora ticinensis* (Gandolfi), specimen no. 282-16, peripheral side, ×100 (specimens nos. 282-14–282-16 are from the Koyas-Dzhilga site, Bed 4, Sample 5505, the *Rotalipora appenninica* Zone of the upper Albian); (7) *Rotalipora gandolfii* Luterbacher et Premoli Silva, specimen no. 282-17, spiral (7a) and umbilical (7b) sides, ×90; (8) *Rotalipora gandolfii* Luterbacher et Premoli Silva, specimen no. 282-18, spiral (8a) and peripheral (8b) sides, ×90 (two last specimens are from the lower Cenomanian Bed 5 of the Koyas-Dzhilga site, Sample 5506).

Plate III



western Ukraine, Northern and Lesser Caucasus, where its stratigraphic range is variably interpreted as corresponding to the terminal Albian, lowermost Cenomanian, or Albian–Cenomanian boundary beds.

(5) A great advantage of the studied sections is their belemnite and inoceram faunas useful for correlation of remote boreal sections.

(6) As is evident from investigation of the Mont Risou section, the high correlation potential of any stratotype can be substantiated only by studying a wide spectrum of micro- and nannofossils. Analysis of planktonic foraminifers from the Crimean sections revealed stratigraphic levels correlative with those characterizing the new Albian–Cenomanian boundary stratotype.

(7) The considered example shows that the correlation is convincing, when pictures of fossils characterizing sections are published. Likewise, only those "new stratigraphic schemes" worth attention, which are supplemented by careful description of leading fossil assemblages.

(8) The study on lithology of "green al_3^3 sandstones" should be focused on the vertical and lateral distribution of tuffaceous material and its petrographic features. Additional data on the mid-Cretaceous volcanism in the Crimean Mountains and adjacent regions are necessary to evaluate *the tephrochronological significance* of pyroclastic material in these sandstones.

We are certain that the Albian–Cenomanian succession in the Kacha–Bodrak interfluve area is a perfect object for further study. In our opinion, the thorough study by all available modern methods will turn it into the intermediate reference section for correlating the Mont Risou Albian–Cenomanian boundary stratotype with Eurasian sections.

We hope that experts in Cretaceous stratigraphy will be interested in collaboration, because one of perfect exposures of the Albian–Cenomanian boundary deposits is located only 200 m away from the Research-Training Center of the Moscow State University.

Reviewers A.B. Herman and K.I. Kuznetsova

REFERENCES

Alekseev, A.S. and Naidin, D.P., Ordered Occurrence of Belemnite Rostra in the Cenomanian Deposits of the Southwestern Crimean Mountains, *Izv. Vyssh. Uchebn. Zaved. Geol. Razved.*, 1970, no. 9, pp. 47–50.

Atlas nizhnemelovoi fauny Severnogo Kavkaza i Kryma (Atlas of the Early Cretaceous Fauna from the Northern Caucasus), Moscow: Gostoptekhizdat, 1960.

Birkelund, T., Hancock, J.M., Hart, M.B., *et al.*, Cretaceous Stage Boundaries—Proposals, *Bull. Geol. Soc. Denmark*, 1984, vol. 33, Parts 1–2, pp. 3–20.

Baraboshkin, E.Yu., New Stratigraphic Scheme of the Lower Cretaceous Deposits of the Kachi–Bodrak Interfluve (Southeastern Crimea), *Vestn. Mosk. Univ., Ser. 4: Geol.*, 1997, no. 3, pp. 22–28.

Bogaets, A.T., Boichuk, G.V., Leshchukh, R.I., *et al.*, New Data on the Albian Deposits in the Northern Zone of Northwestern Crimea, *Geol. Zh.*, 1980, vol. 40, no. 6, pp. 27–34.

Bolli, H., Planktonic Foraminifera from the Cretaceous of Trinidad, *B.W.I. Bull. Amer. Paleontol.*, 1959, vol. 59, no. 179, pp. 257–277.

Bolli, H., Zonation of Cretaceous to Pliocene Marine Sediments Based on Planktonic Foraminifera, *Bol. Inform. Assoc. Venez. Geol. Miner. Petrol.*, 1966, vol. 9, no. 1, pp. 3–32.

Brotzen, F., Die Geologiska Resultaten fran Borrningarna vid Hölviken, *Sver. Geol. Unders.*, 1945, Ser. C, vol. 38, no. 7, no. 465.

Donovan, D.T., The Jurassic and Cretaceous Systems in East Greenland, *Medd. Grønland*, 1957, vol. 155, no. 4, pp. 87–154.

Frieg, C., *Systematische, biostratigraphische und palaëkologische Untersuchungen an agglutinirenden Foraminiferen des Cenomans in Bochum*, Munster, 1979.

Gale, A.S., Kennedy, W.J., Burnett, J.A., *et al.*, The Late Albian to Early Cenomanian Succession at Mont Risou near Rosans (Drôme, SE France): An Integrated Study (Ammonites, Inoceramids, Planktonic Foraminifera, Nannofossils, Oxygen and Carbon Isotopes), *Cretaceous Res.*, 1996, vol. 17, no. 5, pp. 515–606.

Gorbachik, T.N., *Yurskie i rannemelovye planktonnye foraminifery* (Jurassic and Early Cretaceous Planktonic Foraminifera), Moscow: Nauka, 1986.

Gorbachik, T.N. and Krechmar, V., Subdivision of the Aptian–Albian Deposits in the Crimea Based on Planktonic Foraminifera, *Vestn. Mosk. Univ., Ser. 4: Geol.*, 1969, no. 3, pp. 46–56.

Hart, M.B., Carter, D.J., and Leary, P.N., and Talwar A.S.H.D., Agglutinated Foraminiferida from the Albian–Cenomanian Boundary in SE England, *Palaeoecology, Biostratigraphy and Taxonomy of Agglutinated Foraminifera*, London: Kluwer Academic Publishers, 1990, pp. 945–960.

Iolkichev, N., Iovcheva, P., Dimitrova, E., and Stoyanova-Vergilova, M., Stratigrafiya na tsenomanskiya etazh severno ot Pleven i novi mikrofaunistichni danni za polozhkata mu, *Spisan. Blgarskoto Geol. Druzhestvo*, 1988, vol. 49, no. 2, pp. 24–36.

Kaplan, U., Keller, S., and Wiedmann, J., Ammoniten und Inoceramen—Gliederung des norddeutschen Cenoman, *Schrift. Erdwiss. Kommiss., Wien*, 1984, vol. 7, pp. 307–347.

Plate III. Foraminifers from basal Cenomanian beds of southwestern Crimea: (1) *Rotalipora globotruncanoides* Sigal, (1) specimen no. 282-19, spiral (9a) and umbilical (9b) sides, ×90; (2) *Rotalipora globotruncanoides* Sigal, specimen no. 282-20, umbilical side, ×90; (3) *Rotalipora gandolfii* Luterbacher et Premoli Silva, specimen no. 282-21, spiral (3a) and umbilical (3b) sides, ×100; (4) *Rotalipora micheli* (Sacal et Debourle), specimen no. 282-22, spiral (4a) and umbilical (4b) sides, ×100; (5) *Rotalipora micheli* (Sacal et Debourle), specimen no. 282-23, umbilical side, ×100; (6) *Rotalipora micheli* (Sacal et Debourle), specimen no. 282-24, peripheral side; ×100; (7) *Rotalipora caroni* Ion., specimen no. 282-25, dorsal side, (7a) ×120, (7b) ×3000, and (7c) ×15000 (all specimens are from the lower Cenomanian Bed 5 of the Koyas-Dzhilga site, Sample 5506).

Kaptarenko-Chernousova, O.K., Plotnikova, L.F., and Lipnik, E.S., *Foraminifery Ukrainy. Paleontologicheskii spravochnik* (Foraminifera of Ukraine: Paleontological Guide Book), Kiev: Naukova Dumka, 1979.

Karakash, N.I., Lower Cretaceous Deposits of the Crimea and Their Fauna, *Tr. Sankt-Peterburg. O–va Estestvoispytatelei, Otd. Geol. Miner.*, 1907, vol. 32, no. 5, pp. 1–482.

Malchus, N., Revision der Kreide-Austern (Bivalvia: Pteriomorphia) Agypteus (Biostratigraphie, Systematik), *Berlin. Geowiss. Abh., Reihe A*, 1990, vol. 125.

Marcinowski, R. and Naidin, D.P., An Upper Albian Ammonite Fauna from Crimea, *Acta Geol. Polon.*, 1976, vol. 26, no. 1, pp. 83–118.

Maslakova, N.I., *Globotrunkanidy yuga Evropeiskoi chasti SSSR* (Globotruncanidae from the Southern European Part of the Soviet Union), Moscow: Nauka, 1978.

Matrenitskii, A.G., On the Petrographic Difference between Vraconian Deposits and Rocks of Cenomanian Basement in the Bakhchisarai District of Crimea, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1968, no. 6, pp. 158–159.

Maync, W., Cretaceous Stratigraphy of NE Greenland, *Rep. 18th Session Int. Geol. Congr. (London, 1948)*, London, 1952, part 13, p. 288.

Moullade, M., Étude stratigraphique et micropaleontologique du Crétacé Inférieur de la Fosse Vocontienne, *Doc. Lab. Geol. Fac. Sci. Lyon*, 1966, no. 16.

Moullade, M., Zones de foraminiferes du Crétacé Inférieur Mesogeen, *C.R. Acad. Sci., Ser. D*, 1974, vol. 278, pp. 1813–1816.

Naidin, D.P., Biostratographie und Paläogeographie der Oberen Kreide der Russischen Tafel, *Geol. Jahrbuch*, 1969, vol. 87, pp. 157–186.

Naidin, D.P., The Russian Platform and the Crimea, *Aspects of Mid-Cretaceous Regional Geology*, Reyment, R.A. and Bengston, P., Eds., Academic Press, 1981, pp. 29–68.

Naidin, D.P. and Alekseev, A.S., Section of Cenomanian Deposits in the Kacha–Bodrak Interfluve (Crimea), *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1980, no. 4, pp. 11–26.

Naidin, D.P. and Alekseev, A.S., Significance of the Oceanic Drilling Data for Interpretation of Depositional Environment and Habitat Conditions of Cenomanian Fauna from the Crimean Mountains, *Evolyutsiya organizmov i biostratigrafiya serediny melovogo perioda* (Evolution of Organisms and Biostratigraphy of the Middle Cretaceous), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1981, pp. 7–21.

Naidin, D.P., Vanchurov, I.A., and Alekseev, A.S., Methods of Mathematical Statistics in Studying Cenomanian Belemnite Rostra, *Byull. Mosk. O–va Ispyt. Prir. Otd. Geol.*, 1975, vol. 50, no. 4, pp. 81–94.

Plotnikova, L.F., Detailed Subdivision of Albian Deposits in Crimea Based on Foraminifers, *Novye dannye po stratigrafii i faune fanerozoya Ukrainy* (New Data on the Phanerozoic Stratigraphy and Fauna of the Ukraine), Kiev: Naukova Dumka, 1982, pp. 135–138.

Proceedings of Second International Symposium on Cretaceous Stage Boundaries, Bull. Inst. Royal Sciences Natur. Belgique. Sciences de la Terré, Rawson, P.F., Dhondt, A.V., Hancock, J.M., and Kennedy, W.J., Eds., Brussels: 1996, vol. 66-Supp.

Robaszynski, F., Amedro, F., and Caron, M., La limite Cénomanien–Turonien et la Formation Bahloul dans quelques localités de Tunisie Centrale, *Cretaceous Res.*, 1993, vol. 14, no. 4/5, pp. 477–486.

Robaszynski, F. and Caron, M., Foraminiferas planctoniques du Cretacé commentaire de la zonation Europe Méditerraneé, *Bull. Soc. Geol. France*, 1995, vol. 166, no. 6, pp. 681–692.

Robaczynski, F., Caron, M., and Eur. Group Plankt. Foram. Atlas of Mid-Cretaceous Planktonic Foraminifera (Boreal Sea and Tethys), *Cah. Micropaléont.*, Paris, 1979, vol. 1, pp. 1–185, vol. 2, pp. 1–181.

Robaszynski, F., Caron, M., Amedro, F., *et al.*, Le Cénomanien de la région de Kalaat Senan (Tunisie Centrale): litho-biostratigraphie et interpretation sequentielle, *Rev. Paleobiologie*, 1994, vol. 12, no. 2, pp. 351–505.

Sigal, J., Notes sur les genres foraminiferes *Rotalipora* Brotzen (1942) et *Thalmanninella*, famille des Globotruncanidae, *Rev. Inst. France Petrol.*, 1948, vol. 3, no. 4, pp. 95–103.

Sigal, J., Essai de zonation du Crétacé méditerrenien a l'aide des foraminiferes planctoniques, *Geol. Mediterr.*, 1977, vol. 4, pp. 49–108.

Sornay, J., Inocerames, *Cretaceous Res.*, 1981, vol. 2, no. 3/4, pp. 417–425.

Tröger, K.-A., Zu Problem der Biostratigraphie der Inoceramen und der Untergliederung des Cenomans und Turons in Mittel- und Osteuropa, *Newsl. Stratigr.*, 1981, vol. 9, no. 3, pp. 139–156.

Tröger, K.-A., Comparison of the Cenomanian through Middle Turonian Faunas and Facies between Central and Eastern Europe, *Acta Geld. Polon.*, 1996, vol. 46, nos. 1–2, pp. 81–88.

Vasilenko, V.P., *Anomalinidy* (Anomalinids), Leningrad: Gostoptekhizdat, 1954.

Weber, G. and Malychef, V., Sur la stratigraphie du Mésocrétacé et du Neocrétacé de la Crimée, *Bull. Soc. Geol. France*, 1923 (1924), Ser. 4, vol. 23, nos. 5–6, pp. 193–204.

Weber, G.F., Malysheva, V.S., and Neiman, O.F., Subdivisions of the Upper Cretaceous in the Crimea, *Izv. Geolkoma*, 1911 (1912), vol. 31, no 1, pp. 37–39.

Yanin, B.T., *O sootnoshenii obshchikh i mestnykh stratigraficheskikh podrazdelenii nizhnego mela yugo-zapadnogo Kryma (mezhdurech'e Kacha-Bodrak)* (Relationships between General and Local Stratigraphic Subdivisions of the Lower Cretaceous in Western Crimea, the Kacha–Bodrak Interfluve), *Vestn. Mosk. Univ., Ser. 4: Geol.*, 1997, no. 3, pp. 29–36.

Yanin, B.T. and Vishnevskii, L.E., The Cretaceous System. Lower Series, *Geologicheskoe stroenie Kachinskogo podnyatiya Gornogo Kryma. Stratigrafiya mezozoya* (Geological Structure of the Kacha Uplift in the Crimean Mountains: Mesozoic Stratigraphy), Moscow: Mosk. Gos. Univ., 1989, pp. 81–123.

Zonova, T.D., Cretaceous Inoceramids of Eastern Soviet Union. Atlas of Guide Groups of Mesozoic Fauna from the Southern and Eastern Soviet Union, *Tr. Vses. Geol. Inst., Nov. Ser.*, vol. 350, 1992, pp. 172–192.

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 482–490. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 65–73.
Original Russian Text Copyright © 2000 by Kezina, Ol'kin.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Palynological Characteristics of Cenozoic Coal-Bearing Deposits, the Snezhnogorskii Locality in the Verkhnyaya Zeya Basin

T. V. Kezina* and G. F. Ol'kin**

** The Amur Complex Research Institute, the Far East Division, Russian Academy of Sciences, Relochnyi per. 1, Blagoveshchensk, 675000 Russia*

*** Limited Partnership "Antratsit", Pervomaiskii per. 15, Zeya, 676200 Russia*

Received May 21, 1998

Abstract—Cenozoic coal-bearing deposits of the Verkhnyaya Zeya basin are of economic interest in the basin marginal areas, where some beds are suitable for open mining of brown coal. The exploratory work at the Snezhnogorskii coal measures was accompanied by analytical and palynological investigations. The study provided new data on the geological structure, stratigraphy and coal reserves in the southwestern area of the Verkhnyaya Zeya basin.

Key words: *Cenozoic, coal seams, palynology, stratigraphy*

INTRODUCTION

The Paleogene and Neogene deposits of the Verkhnyaya Zeya basin and their coal-bearing potential are as yet poorly studied, though the brown coal seams were detected by test drilling in the course of geological prospecting over the entire territory of the depression. The remote and almost inaccessible location of the region renders unprofitable the detailed exploration and estimate of coal reserves in the basin, though the coal demand is steadily increasing in the Zeya region.

The geological structure of the depression and its coal-production potential were described by V.A. Barvenko, who used the materials obtained in 1973–1979 during the geological and geological–hydrological mapping at the scale 1 : 20000. The coal beds were reached by drilling in the depth range from dozens to few hundreds meters, where their thickness varied from several centimeters to 6–8 m. The most favorable areas for brown coal exploration are located in marginal parts of the Verkhnyaya Zeya basin, where there are beds suitable for open-cut mining with a low stripping coefficient. In 1995–1996, Limited Partnership "Antratsit" carried out prospecting works and evaluated reserves of brown coal in the southeastern part of the basin east of the Snezhnogorskii Settlement, in the basin of the Bol'shaya and Malaya Pal'paga rivers and Babushkin Creek (Fig. 1).

The exploration work was supplemented by analytical research, the palynological study included, and as a result, the principally new information obtained elucidates the geological structure, stratigraphy, and coal reserves of the southeastern part of the Verkhnyaya Zeya depression.

GEOLOGICAL STRUCTURE, COAL-PRODUUCTION POTENTIAL, AND COMPOSITION OF PALYNOLOGICAL ASSEMBLAGES

The Snezhnogorskii locality of coal measures represents a small erosion remnant after a large deposit genetically associated with the Dutkan Formation. This formation is composed of clay and silt beds intercalated with sand interlayers and brown coal seams. The rocks either conformably overlie the Oligocene sands, or discordantly rest on the Cretaceous deposits.

Within the depression, the Dutkan Formation thickness grows from west to east and reaches the maximum (240 m) in the Amakan trough. In the marginal southwestern part, the formation is as thick as 50 m or less. The overlying Temna Formation is composed of kaolin-bearing sands enclosing silt and clay interbeds.

The basal beds of Cenozoic rock sequence in the Verkhnyaya Zeya basin consist of inequigranular alluvial sands intercalated with siltstone, clay, and brown coal interbeds. The beds are conditionally dated back to the Paleogene (Akhmet'ev, 1986).

The most complete sequence of these beds was recovered by the borehole 2T (the depth range of 328–107 m) in the Dutkan trough during the medium-scale geological mapping of 1973 under the leadership of V.A. Barvenko. Similar deposits were penetrated in the Sirik trough (borehole 6T, 490 m) of the watershed area separating the Bol'shoi and Malyi Tanuk rivers, and also in the Amakan trough located in the estuary of Malaya Burgali River (borehole 2B, 400–325 m; borehole 3B, 423–395 m). In the northern part of the depression, near its boundary, the Oligocene deposits were detected in the Topangra River valley (borehole 9T,

147–35 m) and on the right-hand bank of the Urkan River in its estuary (boreholes 2G and 5G). The sequence discordantly overlies the Upper Cretaceous deposits of the Pal'paga Formation (K_2pl), being overlain by sandy–clayey strata of the Dutkan Formation (Fig. 2). In the axial part of the depression, where the sequence is thickest, L.I. Lukashova and N.D. Litvinenko distinguished two palynological assemblages of the Paleogene: one with predominant Polypodiaceae and another consisting of coniferous, broad-leaved, and Taxodiaceae pollen the late Oligocene in age.

At the site of the Snezhnogorskii coal measures, the Paleogene deposits are les than 10–15 m thick. They are composed mainly of sand enclosing clay and coal interbeds, and their palynological characteristics were studied in samples recovered by boreholes 7 (depth levels of 22.1 and 32 m), 64 (11 and 16 m), 8 (29.8 m), and 59 (15.2 m). All samples yielded the Snezhnogorskii palynological assemblage SPA-I, where pollen of abundant small-leaved boreal angiosperms is dominant (up to 68.4%). Pollen of Betulaceae (*Betula* sp., *Alnus* sp., *Corylus* sp.) represents the larger part (31.9%) of angiosperm taxa. The list of moderately thermophilic plants includes Juglandaceae (genera *Juglans, Carya, Platycarya, Pterocarya,* and *Engelhardtia*) and Fagaceae (up to 4.5%), mainly *Quercus conferta* Boits., *Quercus dentata* Boits., and *Fagus grandifoliiformis* Boits. Associated pollen of more thermophilic and subtropical plants represents *Liquidambar* sp., *Celtis* sp., *Magnolia* sp., *Rhus* sp., *Platanus* sp., and *Comptonia* sp. The group of Ulmaceae (up to 6.4%) includes pollen of *Ulmus* sp., *Zelkova* sp., *Plancra* sp., and single pollen grains of *Ulmoideipites tricostatus* And. and *Ulmoideipites krempii* And. comparable with their modern varieties (probably, redeposited). Pollen of Moraceae, *Aralia* sp., *Tilia manshurica* Kupr. et Max., *Myrica* sp., and *Ilex* sp. is persistently present in a small proportion (0.3–1.5%). Formal taxa are represented by single finds of *Triporopollenites* sp. and *Tricolpites* sp. The herbaceous–fruticulose group of the spectra includes pollen of Ericaceae (up to 22%) and of less abundant Rosaceae, *Lonicera* sp., and *Diervilla* sp.

The content of gymnosperms reaches 17.7–44.2%. Dominant in this case are Pinaceae (up to 36.1%), represented by genera *Pinus*, Piceae, *Tsuga* (up to 8.2%), and by less abundant *Cedrus, Podocarpus, Dacrydium,* and *Abies*. In the Taxodiaceae group, representatives of the valley and even aquatic phytocoenoses are diverse. The palynological assemblage considered above correlates well with the pollen assemblage from the upper subformation of the Chernaya Rechka Formation in the Central Amur depression (Ziva and Lukashova, 1977).

The analyzed palynological assemblage differs from that of the Mukhino Formation in the Ushumun basin (Mamontova, 1975) by a somewhat higher content of the small-leaved Betulaceae and also by absence of the relict Eocene pollen *Pistillipollenites* and *Aquilapollenites*. Apparently, the difference is conditioned

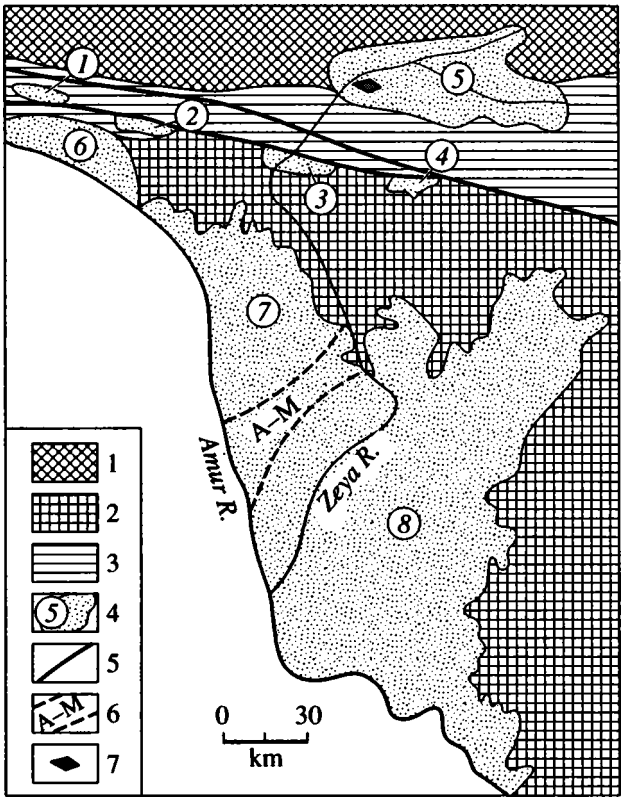


Fig. 1. Scheme illustrating geology and structural position of Cenozoic depressions in the Amur River upper courses (after Krasnyi, 1980, and Varnavskii, 1977, with modifications) (Scale 1 : 1 500 000): (1) areas of Precambrian and Baikalian folding; (2) areas of Paleozoic folding; (3) areas of Mesozoic folding; (4) Cretaceous–Cenozoic depressions Urusha–Oldoi (*1*), Urkan (*2*), Pikan (*3*), Dep (*4*), Verkhnyaya Zeya (*5*), Ushumun (*6*), Amur–Zeya (*7*), and Zeya–Bureya (*8*); (5) disjunctive dislocations; (6) Amur–Mamyn outlier; (7) area of the Snezhnogorskii coal measures.

by the volume of the Mukhino Formation including not only the upper Eocene and lower Oligocene deposits, but also the older middle Eocene beds of the Ushumun depression.

Beds with a higher Pinaceae content were recognized by Sedova (1956) in the lowermost Oligocene horizons in the Suputinka area of the Primor'e region and also as a member of the Uglovoe Formation near Vladivostok. The described palynological assemblage is well correlative with the sixth palynological assemblage identified by N.S. Gromova and L.A. Baskakova in the Nadezhdenskoe Formation of the Rechnoi Peninsula and in the middle part of the coal-bearing sequence of the Shkotovo depression (Gromova, 1967).

According to data of Akhmet'ev *et al.* (1978), deposits comparable in age, which are naturally exposed and recovered by drilling in the Rechnoi Peninsula, yield the floral assemblage of *Metasequoia occidentalis* and *Trochodendroides arctica* associated with dominant representatives of Ulmaceae. This level

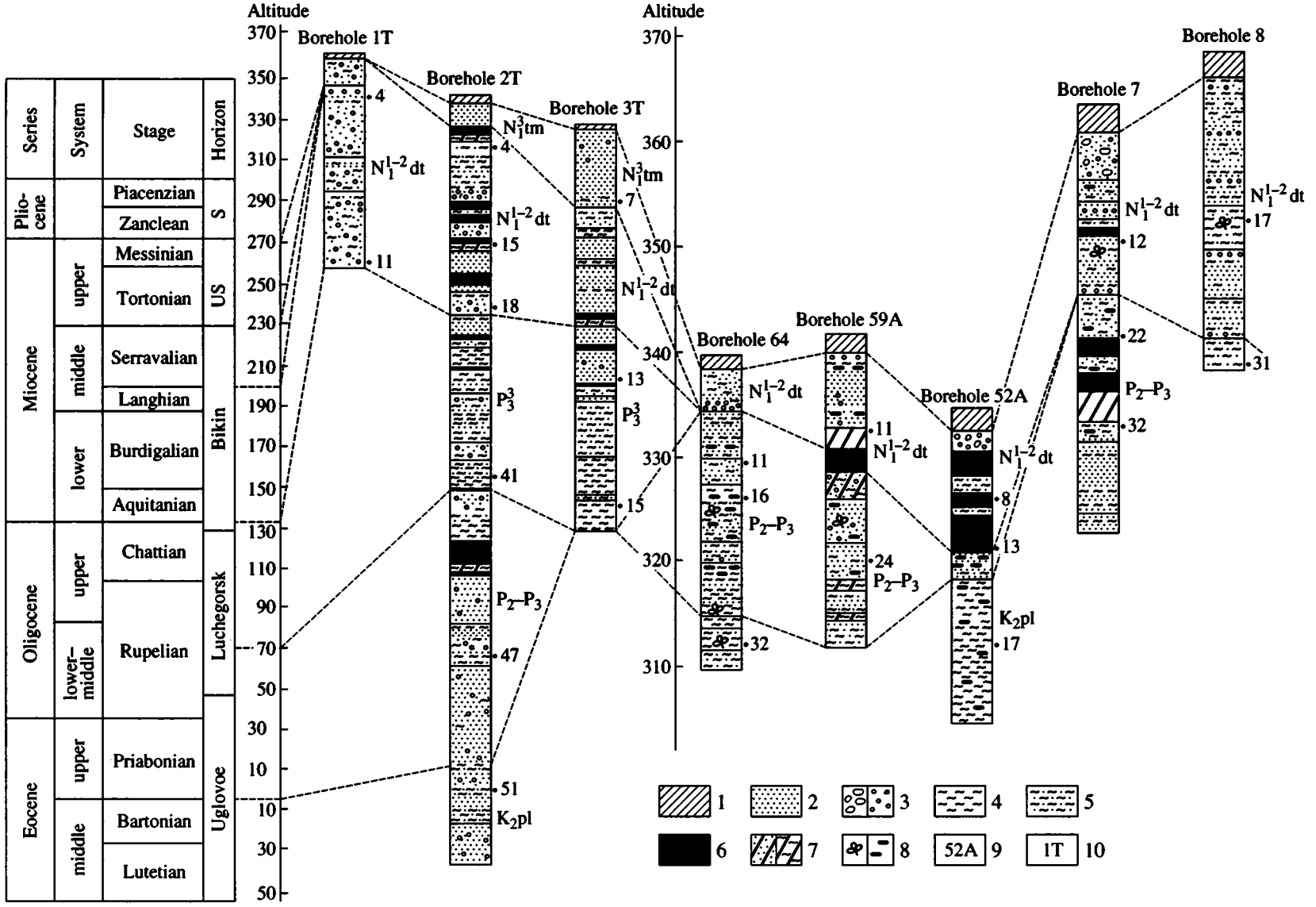


Fig. 2. Correlated sections of the Verkhnyaya Zeya depression: (1) diluvial deposits; (2) sand; (3) pebbles and gravel; (4) clay; (5) silt; (6) brown coal; (7) coaly sand or clay; (8) plant remains and detritus; (9) test boreholes in the Snezhnogorskii area; (10) hydrological test boreholes of the Tulunga Mapping Party (1973). Indices of stratigraphic units: (US) Ust'-Suifun Horizon; (S) Suifun Horizon; (K_2p) Pal'paga Formation; (N_1^{1-2}) Dutkan Formation; (N_1^3 tm) Temna Formation.

probably corresponds to the terminal Eocene, or to the very beginning of the Oligocene.

Data presented above suggest that deposits bearing SPA-I can be dated back to the late Eocene–early Oligocene (Priabonian–early Rupelian; Fig. 2). Age of similar pollen assemblages is likewise interpreted in the stratigraphic zonation adopted at the IV Interdepartmental Regional Stratigraphic Meeting (*Resheniya...*, 1994).

The spore–pollen assemblage from overlying deposits greatly differs from the assemblage under discussion. This one is characteristic of the Dutkan Formation consisting of thick clay and silt beds with sand and brown coal interlayers almost everywhere in the Verkhnyaya Zeya depression. In the western and central parts of the depression, the formation concordantly rests on the Oligocene sands, whereas in the northern and eastern parts it discordantly overlies the Lower Cretaceous sediments.

The lower boundary of the Dutkan formation is conditionally drawn at the base of the basal silty horizon enclosing brown coal seams. Lithological composition of the formation varies over the depression area. For instance, fine-grained sands, silts, clays, and brown coal seams dominate in its central part, whereas abundance of gravel, shingle and inequigranular sand increases towards the northern, southern and western flanks, where interbeds of brown coal and coaly clay are thinner and less frequent. Within the Snezhnogorskii coal measures proper, the Dutkan Formation is composed of clay and silt intercalated with sand interlayers. In its upper part, there are brown coal beds up to 5 m thick. The formation is exposed on the surface only in the river bank slope, 3 km to the north of the Snezhnogorskii Settlement. In other areas, the formation is overlain by younger deposits of the Temna and Arga formations.

Borehole 2R was drilled in the Chernaya Rechka valley and recovered seven coal beds of the Dutkan Formation. In the depth interval from 17.6 to 230.7 m below the surface, the coal bed thickness varies from one to six meters. The basal horizon of the formation is 2 to 10 m thick and consists of gray fine-grained clayey sand. Higher, there is a brown coal bed 4.5–5 m thick (boreholes 52, 51A, 54). The same bed was also penetrated under the Quaternary deposits in a small erosion window.

Palynology of the Dutkan Formation is characterized (SPA-2) by the samples recovered from the boreholes 59A (11 and 11.5 m), 52A (8.5 m), and 8 (17 and 29.8 m). Spores and pollen from the samples are diverse in composition and show domination of angiosperms (up to 69.4%).

The most abundant is the pollen of the small-leaved Betulaceae (*Betula* sp., *Corylus* sp., and *Alnus* sp.; up to 35.6%). These taxa associate with Pinaceae, among which *Pinus* genus is dominant (*Pinus* s/g *Haploxylon*, *Pinus* s/g *Diploxylon*, and *Pinus* sp.). Abundance of Taxodiaceae is considerably lower (not more than 8.7%). In addition to pollen of *Taxodium* sp., this group includes single pollen grains of *Sequoia* sp., *Metasequoia* sp., and *Glyptostrobus* sp.. The assemblage also includes a small amount of pollen of *Podocarpus* sp., *Dacrydium* sp., and *Araucaria* sp. (abundance rate up to 1.5% for each taxa), as well as single pollen grains of *Ginkgo*. The *Tsuga* genus is represented by several species: *Tsuga diversifolia* (Max) Mast., *T. canadensis* L. Carr., *T. torulosa* Zakl., *T. crispa* Zakl., and *Tsuga* sp. The pollen of the dark conifers (*Picea, Tsuga*) is quite abundant and even subdominant in several spectra.

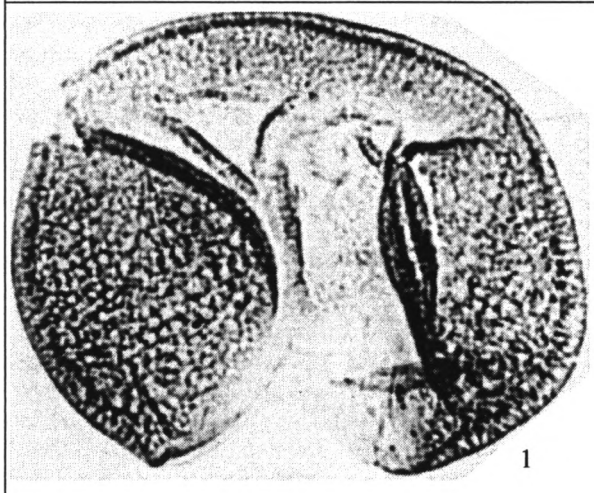
The broad-leaved, moderately thermophilic taxa *Juglans* sp., *Juglans polyporata* Vojc., *Carya exilis* Pan., *Carya* sp., *Carpinus* sp., *Quercus* sp. (up to 2%), *Fagus* sp. (up to 5.9%), *Ilex* sp. (up to 4.7%), *Tilia manshurica* Kupr. et Max., *Tilia* sp., *Ulmus* sp., *Zelkova* sp., *Myrica* sp., *Aralia* sp., and *Rhus* sp. are persistent and sometimes significant components of the palynological spectra. Pollen of these taxa associate with less frequent and single pollen grains of *Pterocarya* sp., Hamamelidaceae, *Liquidambar* sp., and *Castanea* sp.

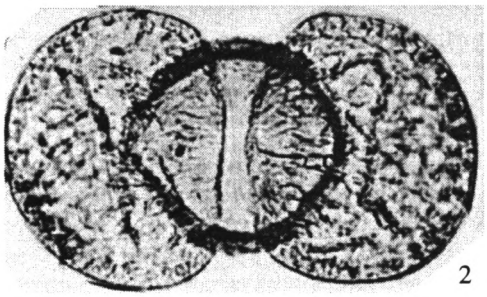
At the level under consideration, there is a notable growth of the herbage pollen content, first of all, of Gramineae (up to 2.7%), Cyperaceae (up to 3.4%), and *Persicarya* (up to 4.7%), and also of Lileaceae, Polygonaceae, Compositae, and Ericaceae (up to 16.3%). These taxa associate with fruticose Rosaceae and Caprifoliaceae. The vegetation of water basins is represented here by pollen of *Nelumbo* sp. and *Trapa* sp., and also by spores of *Lycopodium*. The last group is characteristic of lacustrine–marshy landscapes and indicates a considerable humidity of climate. Abundance of sporogenous taxa in palynological spectra is unstable and varies from 7 to 30.1% owing to the variable content of Polypodiaceae (ferns) and *Sphagnum* sp. (mosses). Accessory spores are those of *Bryales, Botrychium*, Ophioglossaceae, and *Adianthum*.

Quantitative proportions of taxa vary depending on the spectrum position in the formation section. As shown by boreholes drilled in the central part of the depression, the climatic optimum is recorded either in the middle (boreholes 2T, 5T, 6T, 2b, and 6B) or in the upper parts of the section (boreholes 3T, 13T, and 3A). Palynological spectra indicative of the optimum are enriched in pollen of thermophilic plants, in particular, of Juglandaceae, Fagaceae, *Tilia* sp., and *Ilex* sp. In the Snezhnogorskii coal measures, palynological indications of the climatic optimum are less obvious. Distribution patterns of pollen of thermophilic broad-leaved plants are fairly uniform, but the deposition time of coal beds might be corresponding here to the optimum.

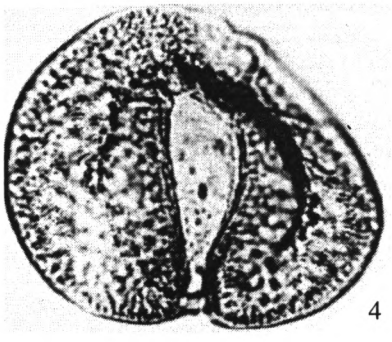
As compared with SPA-1, SPA-2 characterizing the marginal part of the depression shows a larger amount of coniferous pollen and somewhat decreased abundance of pollen exemplifying herbs and valley vegetation (larch, willow, elm, alder). This indicates a considerable influence of adjacent mountain and piedmont

Plate I


1

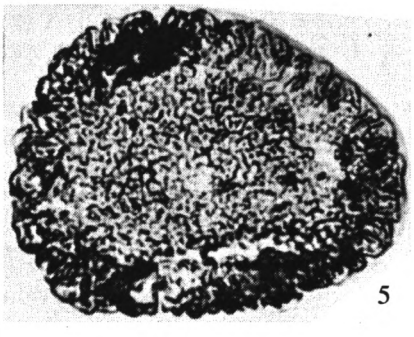

2

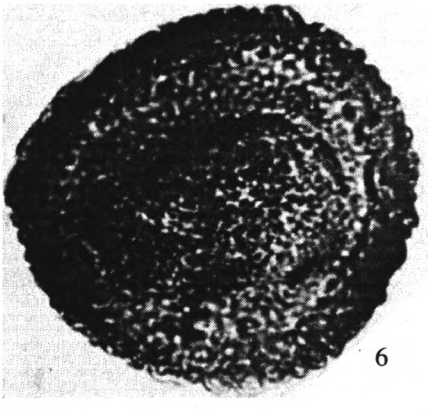
3


4

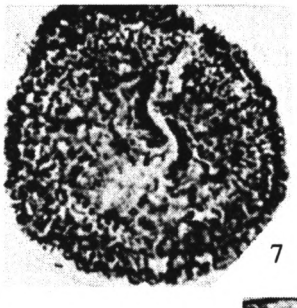
10

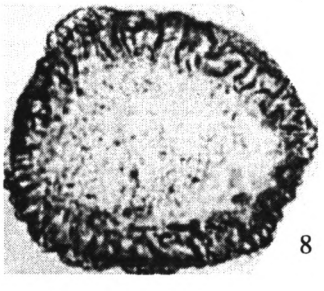
11


5

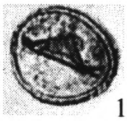

6

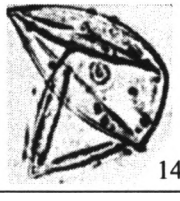
12


7


8

9


13


14

15

16

landscapes. In general, SPA-2 retains the taxonomic composition of the first assemblage, but the corresponding flora of the Turgai ecotype was considerably impoverished in marginal zones. Judging from changes in flora composition, the seasonal climate of the zones approached that characterizing continental areas. This is evident from disappearance of many tropical and subtropical species, and also from the higher abundance of herbaceous and small-leaved boreal vegetation that included birches, alders, elms, and willows. The climate was moderately warm, but drier as it is implied by the flora taxonomic composition and abundance rates of constituent taxa.

The palynological assemblage under consideration corresponds to the forest vegetation mostly consisting of plants typical of the mountain and piedmont landscapes. Along the banks of rivers and water basins there were islets of the *Taxodium–Myrica* swamp assemblage and the valley forests with alder, birch and willow. The lowland and piedmont areas were overgrown with coniferous–broad-leaved forest that included *Quercus, Juglans, Ulmus, Carpinus*, and underbrush of Caprifoliaceae and Ericaceae. Large areas were covered with meadows and swamps.

The described spore–pollen assemblage correlates well with that from the lower coal-bearing subformation of the Ushumun Formation of the Central Amur depression. Ziva and Lukashova (1977) macerated the latter assemblage from clayey–silty deposits enclosing interbeds and lenses of sand and brown coal. According to G.G. Martinson, the Ushumun Formation is of the late Oligocene–early Miocene age according to the fossil freshwater fauna collected from the coal-bearing interval of the formation. Akhmet'ev *et al.* (1969) and A.M. Kamaeva (see in Varnavskii, 1971) attributed the formation to the Miocene on the basis of the foliate flora considering it as typical of this stage in the Far East vegetation evolution.

A comparison of the SPA-2 with palynological assemblages from the Amur–Zeya depression reveals its similarity with flora known from the northeastern distribution area of the Buzuli Formation. The formation is of the early Miocene age (Aquitanian–Langhian). The assemblage is also similar to palynoflora from the Ust'-Davydovo Formation of the Razdol'nenskaya depression (the southern part of the Primor'e area, the Komarovka River basin), where it is dated back to the early Miocene (Bolotnikova, 1979).

The above data conclusively show that the Dutkan Formation of the Verkhnyaya Zeya depression is an age analog of the Buzuli Formation of the Amur–Zeya depression and of the Ushumun Formation of the Central Amur depression. It should be attributed to the lower–middle Miocene. In the regional stratigraphic scheme, it is shown as a part of the Bikin Horizon.

In the Snezhnogorskii coal measures, the Dutkan Formation underlies the kaolin-bearing inequigranular sands intercalated with interbeds of light gray clay and silt. In the Tulunga area, N.F. Levykin distinguished deposits of a similar lithological composition as a unit of polymictic sands (boreholes 2T and 6T; Fig. 2) that was later attributed to the Temna Formation (Barvenko and Sorokin, 1977). In the central part of the Verkhnyaya Zeya depression, this formation conformably overlies the Dutkan Formation, and its lower boundary is conditionally drawn along the roof of silty–clayey deposits enclosing the brown coal interbeds and seams.

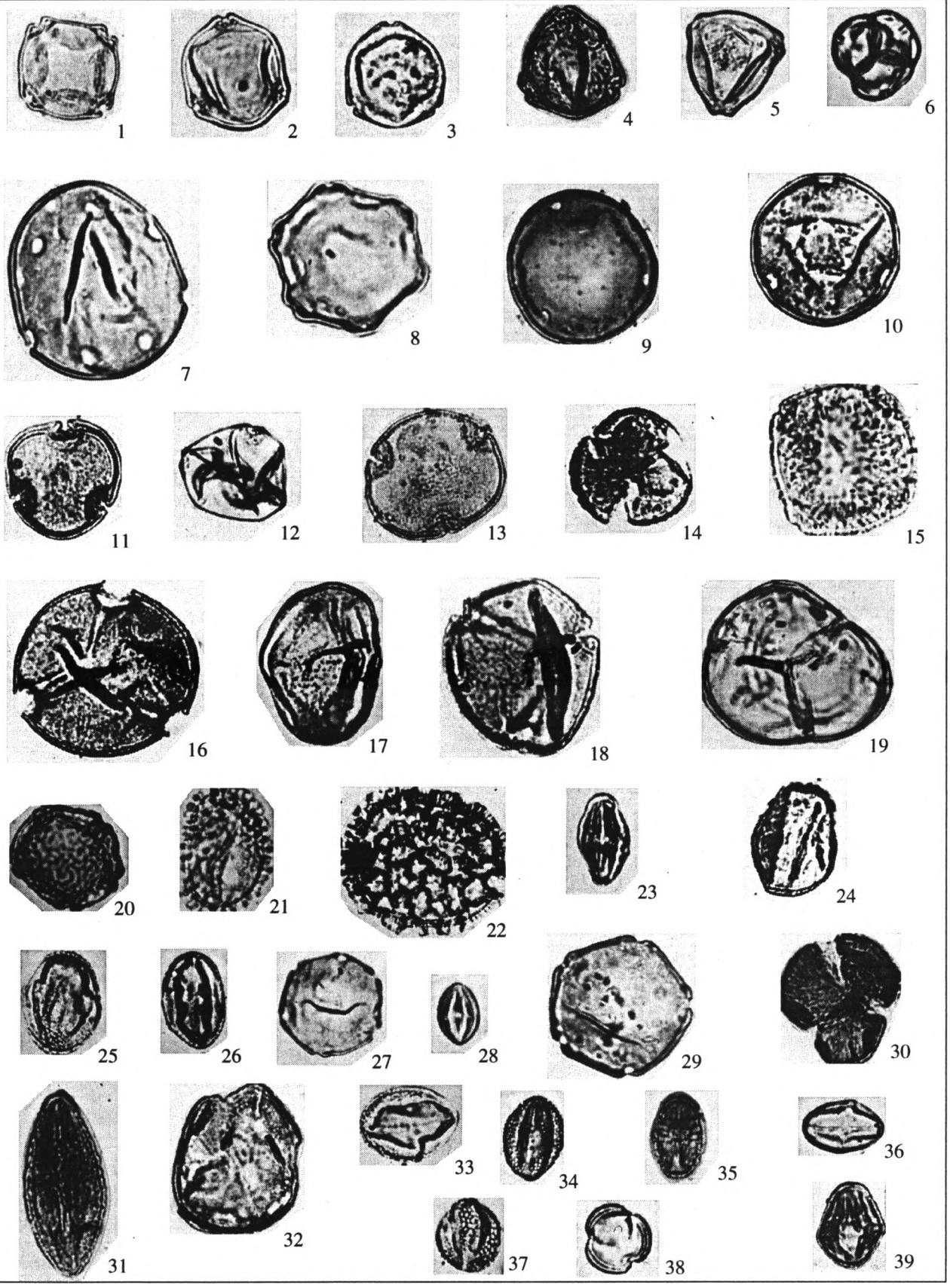
Palynological analysis of samples from borehole 65 in the study area demonstrated that the beds overlying the Dutkan Formation yield palynoflora similar in composition to the SPA-2 characterizing the latter. It is likely that the beds are of the middle Miocene age, but geologists busy with sedimentary cover mapping in the Verkhnyaya Zeya depression consider them, without sufficient proofs, as the upper Miocene strata.

In the southeastern part of the depression, the Temna Formation is composed mainly of light gray and white inequigranular quartz–feldspar kaolinitic sands. The formation encloses rare interbeds of immature brown coal up to 1.4 m thick and interlayers of black coaly clay up to 0.8 m thick. According to Barvenko and Sorokin (1977), the upper Miocene deposits of the Temna Formation are exposed at the day surface in the Arga, Un'ya, and Urkan river valleys; they were also penetrated by boreholes in the Malaya Burgali and Amakan river basins.

According to Lukashova who studied the palynological assemblage from borehole 2T that penetrated the Temna Formation (Varnavskii *et al.*, 1988), angiosperms, mostly *Betula* and *Alnus* are dominant taxa here (up to 85%). The content of gymnosperms is up to 15 %, and this group includes single specimens of *Podocarpus* sp. and Taxodiaceae associated with scarce pollen of *Pinus* sp. and *Picea* sp.. The broad-leaved plants are represented in the assemblage by moderately thermophilic *Juglans* sp., *Myrica* sp., *Ilex* sp., *Corylus* sp., *Quercus* sp., and *Tilia* sp. Representatives of fruticose group are *Salix* sp., *Viburnum* sp., *Diervilla* sp., *Lonicera* sp., Ericaceae, and some other taxa. The share of herbaceous and fruticose plants pol-

Plate I. Spores and pollen of Cenozoic gymnosperm plants from the Snezhnogorskii coal measures (magnification 800): (1) *Picea protocembra* Zakl. and (2) *Podocarpus* sp., Oligocene, borehole 7 (32 m); (3) *Pinus* s/g *Haploxylon*, Lower-Middle Miocene, Dutkan Formation, borehole 59A (11.5 m); (4) *Picea* sp. and (5) *Tsuga crispa* Zakl., Dutkan Formation, borehole 52A (8.5); (6) *Tsuga canadensis* Carr. and (7) *Tsuga* sp., Oligocene, borehole 8 (29.8 m); (8) *Tsuga torulosa* Zakl. and (9) *Sciadopitys* sp., Lower–Middle Miocene, Dutkan Formation, borehole 8 (17 m); (10) *Bryales* sp., (11) *Sphagnum* sp., and (12) *Taxodium* sp., lower–middle Miocene, Dutkan Formation, borehole 8 (17 m); (13) *Taxodium* sp., (14) Cupressaceae, (15) *Glyptostrobus* sp. and (16) *Taxodium* sp., Oligocene, borehole 7 km (32 m).

Plate II


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39

len is insignificant. The group of sporogenous plants includes Polypodiaceae, *Sphagnum* sp., *Adianthum* sp., and *Bryales* sp.

The Arga Formation of sand, gravel, and pebble beds occupies upper parts of the watershed and nearby areas of the depression. Lukashova and Litvinenko described the alder-birch assemblage with accessory Polypodiaceae from this formation (see in Varnavskii, 1998). Pinaceae and various herbaceous plants are subdominant taxa of the assemblage. Pollen of *Tsuga*, Taxodiaceae, *Juglans, Ilex, Fagus*, and *Carpinus* is sporadic here. Opinions about the stratigraphic range and age of the Arga Formation are as yet controversial.

PHYTOGEOGRAPHY

At the beginning of the Cenozoic, the territory of the Amur River basin was a part of the temperate Boreal region of the Holarctic province. It is well known that the coal accumulation of the Paleogene and Miocene time took place within this region along the periphery of the West Siberian plate, in many East Siberian depressions, the Baikal trough included, in the depressions of the Arctic coast, in the continental part of northeastern Russia, and in the Amur and Primor'e areas. The same events are also recorded in the Pacific mobile belt, Kamchatka and Sakhalin included. The composition of coal-forming associations varied over the region depending on the phytochories with individual climatic conditions. The larger part of coal deposits is composed of higher plant remains and of their gum residue. In general, this matter belongs to the humic degradation type.

At the site of the Snezhnogorskii coal measures, the Oligocene coaly clay accumulated under conditions of oligodominant marshy forests, where plant communities included bog cypresses, heather, and alder. In corresponding palynofloras, the dominant Polypodiaceae spores (up to 36.5%) associate with fairly abundant pollen of spruce (up to 25%), birch (up to 20%), and alder (up to 10%). The content of Ericaceae pollen is about 10%. The interbeds of silt and sand mainly yield pollen of pines (up to 40%) and elms (up to 40%). The content of Polypodiaceae spores is here up 20%, and the *Ilex* pollen is frequently rather abundant. This association of dominant taxa may reflect the combined influence of the lowland and higher plant communities.

The coal-bearing deposits of the Dutkan Formation(N_1^{1-2} dt) show a high content of Polypodiaceae spores (up to 20%) associated with pollen of birches (up to 30%) and heather (up to 20%). This spectrum suggests that the valley vegetation was widespread at that time. The clay and silt beds contain extremely large amounts of pollen produced by pines (up to 40%), *Tsuga* (up to 15–20%), heather (up to 20%), and alder (up to 10%). In the coal beds of the earthy texture, the dominant fraction is represented by *Sphagnum* spores (up to 25%). The pine pollen is very abundant in the clayey siltstones (up to 40%), where it is associated with pollen of *Tsuga* (15–20%), heather (up to 20%), and alder (up to10%). The *Sphagnum* spores (up to 25%) replace those of Polypodiaceae in younger coal beds, and this is responsible for the distinct earthy structure of the latter.

Thus, in the second half of the Paleogene and in the Neogene, vegetation in the study area mostly consisted of Pinaceae and Betulaceae, which, along with Ericaceae and herbaceous plants, gave rise to accumulation of the coal-forming mass. In the Miocene, Betulaceae, Myricaceae, and Ulmaceae became even more abundant among the angiosperms than in the Paleogene. In the course of the middle Miocene climatic cooling, the coal accumulation in the southern part of the Far East rapidly reduced, and by the late Miocene it ceased entirely and did not resume in the Pliocene.

CONCLUSION

The Snezhnogorskii coal measures represent an erosion remnant of deposits genetically associated with the Dutkan Formation (N_1^{1-2} dt, the Aquitanian–Langhian).

In terms of palynology, the coal-bearing and underlying parts of the section are distinct. The former is characterized by SPA-1 that includes representatives of Pinaceae, broad-leaved plants, small-leaved Boreal taxa, and certain subtropical plants typical of the Oligocene deposits in the Far East of Russia. The SPA-2 from the Dutkan Formation has a higher content of pollen of thermophilic plants in the coaly clay beds that accumulated during the period of climatic optimum in

Plate II. Pollen of angiosperm Cenozoic plants from the Snezhnogorskii coal measures (magnification 800): (1) *Alnus* sp.; (2) *Betula* sp. and (3) *Corylus heterophylla* Fish., Dutkan Formation, borehole 59A (11.5 m); (4) *Betula* sp. and (5) *Myrica* sp., Oligocene, borehole 64 (16 m); (6) Ericaceae, Oligocene, borehole 64 (16 m); (7) *Juglans polyporata* Vojc. and (8) *Pterocarya* sp., Oligocene, borehole 7 (32 m); (9) *Carya spakmania* Trav.; (10) *Carya simplex* (R. Pot.) and (11) *Tilia* sp., Oligocene, borehole 8 (29.8 m); (12) *Comptonia* sp.; (13) *Tilia manshurica* Kupr. et Maxim. and (14) *Diervilla* sp., Dutkan Formation, borehole 52A (8.5 m); (15) *Quercus foresdalensis* Trav.; (16) *Fagus* sp. and (17, 18) *Fagus grandifoliiformis* Boits, Oligocene, borehole 7 (32 m); (19) Ericaceae and (20) *Ulmus* sp., Lower–Middle Miocene, Dutkan Formation, borehole 8 (17 m); (21) *Ilex* sp. and (22) *Persicarya* sp., Dutkan Formation, borehole 52A (8.5 m); (23) Labiatae; (24) *Quercus sibirica* Pan. and (25) Oleaceae, Oligocene, borehole 8 (29.8 m); (26) *Rhus* sp., Dutkan Formation, borehole 52A (8.5 m); (27) *Juglans* sp. and (28) *Sambucus* sp., Oligocene, borehole 7 (32 m); (29) *Juglans sibirica* Pan. and (30) *Acer* sp., Dutkan Formation, borehole 59A (11.5 m); (31) *Sterculia* sp.; (32) *Liquidambar* sp.; (33) *Shinus* sp.; (34) *Fraxinus* sp.; (35) Rutaceae and (36) Rosaceae; (37) *Fraxinus* sp., Oligocene, borehole 64 (16 m); (38) *Artemisia* sp. and (39) *Aralia* sp., lower-middle Miocene, Dutkan Formation, borehole 8 (17 m).

the first half of the Miocene. Structural and textural peculiarities of the coal rock series depend on the composition of coal-forming plant assemblages, as the coal proper consists of higher plants remains and their gum residue.

In the Oligocene and during the first half of the Neogene, the accumulation of coal-forming mass at the Snezhnogorskii site was conditioned by wide development of oligodominant valley forests in response to favorable climatic environments.

ACKNOWLEDGMENTS

We are grateful to N.D. Litvinenko from the "Dal'geologiya" Palynological Laboratory, who offered an opportunity to study the palynological collections from the Verkhnyaya Zeya depression, and to M.A. Akhmet'ev for his valuable advices.

Reviewer M.A. Akhmet'ev

REFERENCES

Akhmet'ev, M.A., Beletskaya, S.V., Morozova, V.F., and Salun, S.A., Paleogene and Neogene Deposits in Intermountain Basins, Lower Courses of the Amur River and Western Region of the Sea of Okhotsk, *Sov. Geologiya*, 1969, no. 7, pp. 9–23.

Akhmet'ev, M.A., Bolotnikova, M.D., Brattseva, G.M., and Krasilov, V.A., Stratigraphy and Paleoflora of the Cenozoic Reference Section in the Southern Primor'e, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1978, no. 4, pp. 61–75.

Akhmet'ev, M.A., Volobueva, V.I., Gladenkov, Yu.B., and Sheludchenko, S.D., The Late Paleogene Cooling in the Eastern Soviet Union in Terms of Paleobotanical Data, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1986, no. 4, pp. 87–100.

Barvenko, V.A. and Sorokin, A.P., Cenozoic Deposits in the Verkhnyaya Zeya Basin, *Stratigrafiya kainozoiskikh otlozhenii Dal'nego Vostoka* (Stratigraphy of Cenozoic Deposits in the Far East), Vladivostok: Nauka, 1977, pp. 30–35.

Bolotnikova, M.D., *Sporovo-pyl'tsevye kompleksy tretichnykh otlozhenii Zapadnogo poberezh'ya Yaponskogo morya* (Palynological Assemblages from Tertiary Deposits in the Western Coast of the Sea of Japan), Moscow: Nauka, 1979.

Gromova, P.S., Palynological Assemblages from Paleogene–Neogene Deposits of Southern Primorye, *Stratigrafiya i paleontologiya mezozoiskikh i paleogen-neogenovykh kontinental'nykh otlozhenii aziatskoi chasti SSSR* (Stratigraphy and Paleontology of Mesozoic Deposits in the Asian Part of the Soviet Union), Leningrad: Nauka, 1967, pp. 258–262.

Krasnyi, L.I., *Geologiya regiona Baikalo-Amurskoi magistrali* (Geology of the Baikal–Amur Main Railroad), Moscow: Nedra, 1980.

Mamontova, I.B., Palynological Characteristic and Correlation of Continental Deposits in the Ushumun Basin, *Tr. Sakh. Kompl. Nauchn.-Issl.Inst. Dal'nevost. Nauchn.Tsentr. Akad. Nauk SSSR*, 1975, no. 36, pp. 32–40.

Resheniya IV Mezhvedomstvennogo regional'nogo stratigraficheskogo soveshchaniya po dokembriyu i fanerozoyu yuga Dal'nego Vostoka i Vostochnogo Zabaikal'ya. Khabarovsk (Resolutions of IV Interdepartmental Stratigraphic Conference on the Precambrian and Phanerozoic of the Southern Far East), Khabarovsk: KhGGP, 1994.

Sedova, M.A., Oligocene Palynological Assemblages from Southern Primor'e, the Far East, *Atlas oligotsenovykh sporovo-pyl'tsevykh kompleksov razlichnykh raionov SSSR* (Atlas of Oligocene Palynological Assemblages from Various Regions of the Soviet Union), Moscow: Gosgeotoptekhizdat, 1956, pp. 51–69.

Varnavskii, V.G., *Paleogenovye i neogenovye otlozheniya Sredne-Amurskoi vpadiny* (Paleogene and Neogene Deposits in the Central Amur Depression), Moscow: Nauka, 1971.

Varnavskii, V.G., Sedykh, A.K., and Rybalko, V.I., *Paleogen i neogen Priamur'ya i Primor'ya* (The Paleogene and Neogene of the Amur River Region and Primor'e), Vladivostok: Nauka, 1988.

Ziva, M.V. and Lukashova, L.I., Palynological Characteristic of Paleogene and Neogene Deposits in the Central Amur Depression, *Stratigrafiya kainozoiskikh otlozhenii Dal'nego Vostoka* (Cenozoic Stratigraphy of the Far East), Vladivostok: Nauka, 1977, pp. 42–47.

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 491–497. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 74–81.
Original Russian Text Copyright © 2000 by Fedorov.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Pleistocene Climatic Events in the Geological History of the Black Sea

P. V. Fedorov

Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia

Received September 20, 1999

Abstract—Comparative analysis of Pleistocene climatic events in the Black and Mediterranean seas is used to improve the Pleistocene stratigraphic scale for the Mediterranean region, where beds (terraces) yield tropical molluscan faunas of variable thermophilic affinities. On this basis, the late Chaudan (the epi-Chaudan included) and Sicilian transgressions are correlated with similar events of the Paleouzunlarian and Milazzian times. The Uzunlarian and Paleotyrrhenian phases appear to be also correlative. The Karangatian and Chernomorian transgressive cycles fully correspond to the Tyrrhenian (Riss/Würm) and Flandrian events, respectively.

Key words: *terrace, Tyrrhenian, Milazzian, Sicilian, transgression, regression, Rejiche, Chebba, Douira, Flandrian*

The Pleistocene sequence of the Black Sea area has been long known to include beds with Mediterranean molluscan fauna. Relationships between its beds accumulated in brackish-water and continental settings can elucidate their position in the Pleistocene stratigraphic scale for the entire Pontian–Caspian region.

As far back as 1925, Andrusov (1956) recognized in the Black Sea area the Tyrrhenian terrace, later defined by Arkhangel'skii and Strakhov (1938) as the Karangatian one. I have no intention to discuss here the known problems of the Pleistocene biostratigraphy and correlation of the Black Sea, Caspian, and Mediterranean regions. The main goal of the work is to make the Mediterranean Pleistocene scale more precise analyzing successive events in the Black Sea and Caspian areas.

Although this approach may seem surprising, I believe that the comparative analysis of stratigraphic sequences or event successions around the Black and Mediterranean seas (and subsequently in the World Ocean) is a right way to improve the Mediterranean Pleistocene scale. It is evident that transgressions in the Black Sea could be either equally, or less frequent than in the Mediterranean Sea, because not every transgression was able to overcome the Bosporus threshold. Anyway, I do not think that the interglacial transgressions in the Mediterranean Sea happened less seldom than in the Black Sea.

Around the Black Sea, the following Pleistocene horizons with Mediterranean molluscan fauna are reliably established: Chernomorian, Karangatian, Uzunlarian, and also Paleouzunlarian and Epi-Chaudan not recognized universally as valid. I feel it more convenient to consider these horizons beginning from the upper ones, because the latest events are better understood.

Arkhangel'skii and Strakhov (1938) used the term *Paleochernomorian* to distinguish the Holocene transgression in the Black Sea. Later, all the Holocene stages of the Black Sea evolution were considered as characterizing development of the postglacial Chernomorian transgression. Geological and geomorphological evidences of this transgression are well known in the coastal areas and shallow shelf zone of the sea. They elucidate successive sea level oscillations during that transgressive cycle.

The Flandrian transgression the Mediterranean Sea ("ocean") about 8 or 9 ka ago gradually caused overflow of saline waters through the Bosporus Strait into the Black Sea and resulted in dispersal of Mediterranean fauna there. Apparently, this event may be considered as the beginning of the Holocene Chernomorian transgression. Undoubtedly, the Flandrian transgression began in the Mediterranean Sea somewhat earlier, but it did not cause the considerable sea level rise and significant faunal changes at that moment.

Two major phases in the development of the postglacial Chernomorian transgression can be distinguished: the Paleochernomorian cycle, when the sea level was 10–20 m below its present state, and the basin salinity was lower than at present; and the Neochernomorian cycle, when the sea level exceeded the present one at least by two meters, and the water salinity increased by 20‰ and was higher than now.[1]

The Paleochernomorian clayey sediments with poor Mediterranean fauna rest directly on the Neoeuxinian clays bearing impoverished faunas of the Caspian and freshwater types. Deposits of the Neochernomorian cycle are represented by coastal sands, pebbly gravel,

[1] The current salinity of the Black Sea outside its blackish-water zones is 18‰.

and coquinas. Lithology of these sediments indicates frequent sea level oscillations and coastal abrasion during the transgression. The maximum height of the Neochernomorian terrace is about 4 m (locally, up to 5 m).[2] The concurrent beach ridges and bars, including those in the shallow shelf areas, are lower.

It cannot be excluded that during the Neochernomorian transgression, there were two periods of the comparably high sea level stands. Data on the Kazantipskii Bay terrace in the northern coast of the Kerch' Peninsula show that the first period was long, and the second one was short (for details see Fedorov, 1963, p. 33, Fig. 21). These maximal levels (or level) of the Neochernomorian transgression likely correspond to the highest sea level rise in the Mediterranean Sea and in the World Ocean during the Flandrian transgression, and the corresponding event should be dated back to 5–5.5 ka. Undoubtedly, all interglacial transgressions in the Black Sea were concurrent with those in the World Ocean and Mediterranean Sea.

The Neochernomorian time was characterized by sea level oscillations, major of which were the Fanagorian regression 2.5–3 to 2 ka B.C. ago, when the sea level dropped down to –5 or –6 m (according to some data, even to –7 or –8 m), and the Nymphean transgression about 1 ka ago, when the sea level rose by 0.5–1 m above the present mark.

The Holocene curves of sea-level oscillations in the Black Sea and World Ocean appear to be greatly similar to each other. They could be regarded as identical except for the period of the Fanagorian regression, because Klige *et al.* (1998), plotting the Fairbridge curve, showed here a short-time sea level rise instead of the fall. Nevertheless, the fall of the Black Sea level down to –5 or –6 m at that time is well documented on the basis of geological and archaeological records, and we are able to reliably determine the date and duration of the event.

Bearing in mind the purpose of this publication, I should note that data on the Black Sea history elucidate the disputable sea-level rise of the Fanagorian time in the World Ocean (and Mediterranean Sea) by 1 or 2 m above its present position.

As is known, some ancient Greek buildings are now at the Black sea bottom 5–7 m below the water surface, and some researchers consider this as a result of tectonic subsidence. I should remind, however, that flooded buildings are known along coasts of the Caucasus, Crimea, southern Ukrainian, and Bulgaria, but the older Neochernomorian terraces in the same areas are 4 to 5 m high being intact by tectonic activity.

Thus, the latest peak of the interglacial global Flandrian transgression corresponds to the Chernomorian transgressive cycle that consisted of two, Paleo- and Neochernomorian phases.

The preceding period of the Black Sea history was characterized by the Neoeuxinian transgression, which was independent of ingression of saline Mediterranean or brackish Caspian water masses. This transgression reflects stabilization of the Mediterranean (World Ocean) sea level at the depth mark of 25–30 m, which happened 8–10 ka ago, when the brackish Black Sea was under influence of backwater in the Bosporus Strait. The character of Neoeuxinian deposits yielding brackish-water faunas of the Caspian type and pollen of cold-resistant plants evidences for cool (or moderately cool) climate before the warming during the Flandrian transgression.

In the late Tyrrhenian and post-Tyrrhenian times, the Mediterranean areas still represented the accumulation sites of coastal terrace deposits containing thermophilic faunas, whereas the backwater cessation in the Bosporus Straight caused the water outflow from the Black Sea, salinity of which decreased owing to ingression of brackish waters from the early Khvalynian Caspian basin and also in response to inflow of river waters.

The interglacial Karangatian transgression in the Black Sea at the beginning of the late Pleistocene corresponds to the brightest and magnificent event in the geological history of the region. The transgression was caused by ingression of saline and warm water masses from the Mediterranean basin, where the Tyrrhenian transgressive phase is recorded. This event took place immediately after the post-Uzunlarian regression of a great historical-geological significance. Some Russian and foreign researchers suggest that this regression marking the middle–late Pleistocene boundary corresponds to the Riss Glacial of the Alpine scale (Riss II).

The Karangatian transgression had two major phases: the early and late (or main). The first phase was characterized by the Black Sea expansion into topographic depressions that appeared during the post-Uzunlarian regression. The seawater salinity was not extreme, and sedimentation was predominantly of the clayey type. A short-time regression, which resulted in formation of sand dunes and other landforms, preceded the main phase of the Karangatian transgression, when the sea area increased to the maximum and the sea level rise was greatest, probably attaining +5 or +7 m. The salinity increase up to 30‰ promoted immigration of the Mediterranean stenohaline molluscan fauna. Saline waters flooded river deltas and coastal areas.

The Karangatian regressive deposits are represented by coarse coastal sediments with reworked coquina intercalations. Sometimes, they have been attributed to uppermost beds of the Karangatian Horizon.

The two-member structure of the Karangatian sequence perfectly seen in the Kerch' Peninsula (the El'tigen Village and Lake Chokrak localities) is established as well in some shallow shelf areas, the Kerch'

[2] The 4- or 5-m height of the terrace does not suggest the sea level rise by 5 m because a storm surge during the formation of the terrace is always 2 m and more higher than the sea level.

Strait floor including (Fedorov, 1978). In the Caucasian coast, there are two terraces of the abrasion–accumulation genesis, one corresponding to the lower and another to the upper part of the Karangatian Horizon. Ancient wavemarks of the first terrace are located at the level of about 18–22 m above the sea (up to 30 m in the elevated blocks), and those of the second terrace are detected lower, 12–14 m above the sea. The early Karangatian terrace is locally destroyed, and its fauna displaying stenohaline affinity is not very diverse (Fedorov, 1978). The most diverse stenohaline and thermophilic fauna is characteristic of the late Karangatian terrace preserved almost all along the coast, because the second phase of the Karangatian transgression was more intense. The elevated position of the early Karangatian terrace can be a result of positive tectonic movements in coastal zone between two transgressive phases.

However, it is more important to analyze the most complete Karangatian sections, where two transgressive phases separated by dune sands with shells of terrestrial mollusks are recorded. Exactly these sections are analogues of the Tyrrhenian ones.[3] The transgression peak at the second Karangatian phase and widespread stenohaline fauna from the Black Sea localities show that this event is indeed correlative with the main Tyrrhenian phase (Eutyrrhenian, or Rejiche).

It should be remembered that Keraudren (1971) interpreted the Tyrrhenian as a unit correlative with the Riss/Würm Interglacial in order to distinguish it from other interglacial horizons containing tropical faunas. If this interpretation of two marker horizons can be taken for the reference point, the lower Karangatian Subhorizon of the Black Sea may be an equivalent of the lower Tyrrhenian (Douira) Horizon of the Mediterranean Sea area. As for the late Tyrrhenian (Neotyrrhenian, or Chebba) transgression, it apparently did not advance behind the Bosporus threshold to be recorded in the Karangatian sequences of the Black Sea.

The late Tyrrhenian and post-Tyrrhenian terraces were discovered by Zazo and Goy (1989) in the eastern seashore of Spain. Accumulation of these terraces suggests that the Mediterranean basin was still saline and warm at the beginning of the post-Tyrrhenian regression.

I do not exclude that some low terraces (2–4 m high), particularly those in Spain and North Africa, could be accumulated in the middle Würm time, when sea level in the Mediterranean Sea and other oceanic basins was at the altitude of –40 m and rose afterward. It is also possible that the lowermost Mediterranean terraces locally yielding *Strombus* shells can be interpreted as corresponding in formation time to the Holocene thermal maximum (Paskoff and Sanlaville, 1983). This conclusion is compatible with wide development of the Neochernomorian terraces in the Caucasus, Crimea and southern Ukraine.

Thus, the comparative analysis confirms the idea of Andrusov (1956) that the Karangatian and Tyrrhenian sediments were deposited simultaneously. Recent data show that the succession of Karangatian events reflects even minor details of the Tyrrhenian transgression development. Similarly, the late Flandrian events correspond to particular phases of the Holocene transgression in the Black Sea.

As noted above, the Pleistocene horizons with Mediterranean fauna known around the Black Sea are well correlative with the Pleistocene subdivisions characterizing the entire Pontian–Caspian region. This situation is suitable for analysis of the lower–middle Pleistocene succession and tropical fauna horizons in the Mediterranean region, where fossils are known to differ in the degree of thermophilic affinities. Certainly, this is an indirect correlation, but there is no other way to approach the problem. Radiometric dates are very helpful in this respect, but they are frequently incompatible with geological and geomorphological evidences. The very attractive way of correlation based on terrace positions above the sea level is not always acceptable because of tectonic dislocations. However, the staircase terrace (or the terrace succession) is a reality that must be taken into consideration. The terrace successions can be best recognized in the uniformly elevated coasts, for instance, in the Caucasian and the North African coastal zones, where the Mediterranean terraces are located at the levels of 90–100, 60, 40, 30–35, 20, 10–12, and 3–5 m above the sea. Note how close they are to the levels of the Black Sea terraces in the Caucasian coast. It is hardly a simple coincidence.

Now, let us consider the pre-Karangatian (pre-Tyrrhenian) succession of events in the Black Sea areas. It should be emphasized that the post-Uzunlarian (pre-Karangatian) regression left stratigraphic markers, which are as important as those of the Karangatian time. Deep erosion in deltaic areas of all rivers flowing in the Black Sea, the western Manych depression included (Goretskii, 1970), and overdeepening of the Bosporus Strait down to 100 m resulted in sea water ingression in the river valleys during the Karangatian transgression, when brackish-water fauna populated even limans, for instance, that of the western Manych (Popov, 1983).

Undoubtedly, the regression in question was concurrent with the pre-Tyrrhenian regression predating the Douira Beds of the Mediterranean region. Zeuner (1959) suggested that the former took place between two transgressions: one of "the Great Interglacial" and another of the Tyrrhenian phase proper ("the main Monastirian" in terminology of Zeuner).

Accordingly, Keraudren (1971) was right suggesting to use the term Tyrrhenian only for the Riss-Würm ("last") Interglacial in order to differentiate its deposits from transgressive sediments containing *Strombus* shells. The corresponding regression used to be corre-

[3] During the INQUA Congress of 1982, I headed an excursion to the Caucasus. Observing the late Karangatian terrace, foreign experts on the Tyrrhenian eagerly admitted that it corresponds to the main Eutyrrhenian phase of the Tyrrhenian.

lated with the second Riss/Würm (Moskowian) Glacial. In this case, the Mediterranean fauna appeared in the Black Sea during the interglacial Uzunlarian transgression, sediments of which immediately overlie the upper Paleoeuxinian deposits showing gradual transition to the latter.

Relationships between the upper Paleoeuxinian and Uzunlarian beds suggest that they are members of a single Euxinian–Uzunlarian horizon.[4] It is important in this case that rare euryhaline forms of Mediterranean fauna began to appear in the Paleoeuxinian time to become widespread in the Uzunlarian beds.

In terms of successive events in the Mediterranean region, it seems possible to correlate the uppermost Paleoeuxinian strata and Uzunlarian beds with the terrace sediments of the pre-Tyrrhenian interglacial transgression. Once (Fedorov, 1996), I proposed to name these sediments as Mesotyrrhenian in order to distinguish them from deposits of the older Paleotyrrhenian terrace. However, the current comparative analysis suggests another solution.

There were two phases in the Paleoeuxinian–Uzunlarian cycle (the Euxinian–Uzunlarian II). The first one corresponded to the early Khazarian ingression of Caspian waters into the Black Sea in response to the backwater effect in the Bosporus Strait. The second phase marks the maximum expansion and extreme salinity of the Uzunlarian basin at the peak time of the Mediterranean interglacial transgression. It is evident that the analogous two-phase cycle (the Euxinian–Uzunlarian I) preceded the Euxinian–Uzunlarian II.

In the Caucasian coast (in deltaic areas of the Debug, Ashe, Makopse and other rivers), there is the lower Paleoeuxinian terrace up to 60 m high and the superimposed Paleouzunlarian terrace 45–50 m high. Biostratigraphic characteristics of both are known (Fedorov, 1978). At the lower level, there are the upper Paleoeuxinian and Uzunlarian terraces (40–43 and 35–37 m high, respectively), which are traceable all along the Caucasian coast.

The two-member structure of the middle Pleistocene in the Black Sea areas (the Euxinian–Uzunlarian I and II) was confirmed by the deep-sea drilling data obtained by "Glomar Challenger" in 1975. On the basis of diatom and spore–pollen data, A.P. Jouse, V.V. Mu-khina, and E.V. Koreneva (*Geologicheskaya...*, 1980) recognized a continuous sequence underlying the undisputable Karangatian beds. This sequence recorded three phases of salinity changes and climatic warming, which are well correlative with the Uzunlarian, Paleouzunlarian (units of the middle Pleistocene), and epi-Chaudan (the lower Pleistocene).

It is noteworthy that two large transgressions in the World Ocean occurred in the middle Pleistocene, 300 and 200 ka ago. The temperature rises in oceanic water during these transgressions were synchronous with changes in solar activity (Klige *et al.*, 1998, with reference to data of Fairbridge and Milankovitch). The continental middle Pleistocene sequence in the Russian Plain is of the two-member structure as well (Vasil'ev, 1997). Thus, the events preceding the Karangatian transgression in the Black Sea correspond in full measure to events of the interglacial transgression (Tyrrhenian I in terminology of Zeuner, 1959) and subsequent regression (Riss II).

Bonifay (1975) interpreted the same events as the succession of "the Eotyrrhenian-I (?) transgression maximum" (radiological dates 160–170 ka), subsequent regression, and second transgression maximum at the time of 120–90 ka ago (an analogue of the Riss/Würm Interglacial, or the Tyrrhenian proper).

According to Bonifay, the lower terraces still containing the *Strombus* fauna accumulated 70–32 ka ago during the Würm Glacial and should be attributed to the Neotyrrhenian. It is evident that they are younger than the Tyrrhenian (Riss/Würm) beds and accumulated at the time the post-Karangatian regression in the Black Sea. For these reasons, these and older (Paleotyrrhenian) terraces should not be considered as markers of the Tyrrhenian events, as it was recently done by A.A. Svitoch, A.O. Selivanov, and T.A. Yanina, who made a step backward, in my opinion. It seems that the Neotyrrhenian should be excluded from the Tyrrhenian and altered into the post-Tyrrhenian. My term "Mesotyrrhenian" (Tyrrhenian I of Zeuner, 1959, and "first transgression maximum" of Bonifay, 1975) should be also given up.

The event succession in the Black Sea area shows that the Uzunlarian, but not the Paleouzunlarian transgression is an analogous of the Paleotyrrhenian transgression, because they both took place before the Karangatian–Tyrrhenian. Consequently, the pre-Tyrrhenian regression in the Mediterranean Sea should be synchronous with the post-Uzunlarian regression in the Black Sea.

The interglacial transgression of the Riss Interstadial must be recorded in the Mediterranean region. Otherwise, the Uzunlarian transgression in the Black Sea, which corresponds to the Odintsovo warming 180–200 ka ago (the Riss-I/Riss-II Interglacial), would never happened.

Zeuner (1959) reported on two Tyrrhenian-I (hence, Paleotyrrhenian) terrace levels equal to 30–35 and 40–45 m, which are as high as the Uzunlarian and upper Paleoeuxinian terraces, respectively. I do not intend to base correlation between terraces on their heights. However, the above similarity in their levels, like the coincident levels of all terraces in the Caucasian Black Sea coast and Mediterranean region, is not a chance phenomenon, though we have to analyze in this case not only synchronism of transgression–regression cycles, but also the character and amplitude of elevations of large coastal areas around the basins.

To continue the retrospective analysis, I should consider now events predating the Riss Glacial and corre-

[4] The horizon name as it was used in my previous publications, but now I do not insist on this.

sponding regression in the Black Sea region that determined geomorphological relationships between the lower and upper Paleoeuxinian terraces (60 and 40–43 m). As a result of block movements against the background of uniform uplift in deltaic areas of the Ashe, Makopse, Nebug and other rivers, the lower terrace was elevated and escaped overlapping by the younger, late Paleoeuxinian and Uzunlarian terraces, as was typical of many areas of the Caucasian coast.

The Paleouzunlarian transgression in the Black Sea corresponds to the maximum of the early Paleoeuxinian–Paleouzunlarian megacycle that succeeded the long-term Venedian (Mindel) regression. This regression is also recorded in the Caspian region, where it corresponds to a significant historical-geological level well substantiated by tectonic and paleontological data. The gradual evolution of molluscan fauna across this level (the Baku–early Khazarian or early Paleoeuxinian boundary) undoubtedly evidences in favor of long duration of the regression stage.

I consider the above transgression as connected with the similar event in the Mediterranean, where, according to Zeuner (1959), it occurred during the first Interglacial (Mindel/Riss?) and Milazzian. However, the Milazzian is estimated to be older (350–400 ka) as one can judge from the oxygen-isotope variation curve.

Provided similar tectonic environment, the early Paleoeuxinian and superimposed Paleouzunlarian terraces of the Caucasian Black Sea coast (60 and 50 m high, respectively) appear to be as high as the Milazzian terrace, which is known to contain the warm-water molluscan fauna in contrast to cool-water fauna of the Sicilian terrace. Correlating the Milazzian with the uppermost Chaudan (Epi-Chaudan) in my previous publications, I think now that this problem needs to be studied further. Otherwise, there will be no need to introduce the term "Mesotyrrhenian," because the Uzunlarian should be considered as correlative with the Paleotyrrhenian. It was the opinion of Muratov (1960) and mine (Fedorov, 1964). We should take into consideration here that the Uzunlarian (or Euxinian–Uzunlarian-II) corresponds to the large transgressive cycle, though the water salinity in the Black Sea did not rise significantly because of two factors: this transgression was less extensive than the Karangatian one, and an enormous mass of Caspian water penetrated at that time through the Manych Strait into the Black Sea depression to dilute the Mediterranean inflow. The same controlling factors could be in action during the earlier Euxinian–Uzunlarian-I cycle. The Karangatian transgression developed when ingression from the Caspian Sea ceased, and this explains why the Paleouzunlarian and Uzunlarian transgressions were not as remarkable in the Black Sea history as the Karangatian one, although they could be related to Mediterranean events of comparable significance.

When analyzing terraces (or terrace successions), we can compare, along with the height, their denudation degree. The most striking moment is that the ancient coastlines of the Black and Caspian seas, being above the sea, have almost the same level at different sides of the Caucasus Ridge. For instance, the Baku terrace is 200–220 m high in the southern Daghestan and northern Azerbaijan coasts being risen up to 230–250 m in some local elevations of the southeastern Caucasus. This feature observable in the Caspian coast sector from Makhachkala to the Apsheron Peninsula represents a result of the general Caucasus rise concurrent with folding events. The general rise of ancient coastline and terraces is also characteristic of the Black Sea coast. As a result of the block movements, the difference between terrace heights can be up to 5–20 and even 40 m. The different preservation state of terraces is apparent. For example, the Baku terrace of the Caspian coast represents a series of remnants, surface of which can be visually integrated. At the same time, the early Khazarian terraces are better preserved. In the Caucasian coast of the Black Sea, remnants of the Chaudan terrace 95–100 m high can be traced for a long distance, though it is preserved to a much lesser extent than younger terraces of the Euxinian–Uzunlarian time. The insignificantly deformed late Karangatian terrace 12–14 m high extends almost everywhere along the coast.

The terraces older than those of the early Pleistocene seem to be preserved only as rare mesa forms of the relief, and this is a common natural result of denudation. In this respect, the Chaudan terrace is resembling better the 100-m-high Sicilian terrace than the better preserved Milazzian one. Certainly, this is a very problematic aspect, and any correlation between the Chaudan and Sicilian or Milazzian corresponding to the warming phase is disputable.

As for the Sicilian cool-water fauna, it cannot be indicative of the terrace formation environment. It is evident that the terrace can be formed in the course of abrasion, transgression, and subsequent elevation. It also can be supposed that the terrace originated during the interglacial (or interstadial) transgression under moderate to cool climatic conditions. This is not surprising, because the Flandrian transgression that developed, when climate was cool, increased the sea level from –100 or –130 m to +2 m.

The same events are recorded in the Black Sea region, where the Chaudan transgression developed like the subsequent Euxinian–Uzunlarian cycle. The Chaudan sections in the Kerch' and Taman' peninsulas (Fedorov, 1978, 1993) illustrate development of transgression, shore abrasion and terrace formation. Subsequently, the terrace was risen up and affected by denudation. The Chaudan transgression was conditioned by the backwater effect in the Bosporus Straight during the Mediterranean interglacial transgression.

Provided that above processes developed concurrently, we can evaluate the climatic conditions of the Chaudan time. The commencement of transgression corresponded to the relatively cool climatic phase (the

Correlation of main Pleistocene events in the Black and Mediterranean seas

Oceanic level stand (A.O. Selivanov in Klige *et al.*, 1998)	Mediterranean Sea (published data in my interpretation)		Black Sea		Russian Plain (nomenclature of horizons after Vasil'ev, 1997)
High	Flandrian transgression (from –30 to +2 m)		Chernomorian transgression (from –20 to +2 m)		
Low (noticeable regression)	Early Flandrian transgression (from –50 to –30 m)		Neoeuxinian transgressive phase (sea level stabilization at –40 to –20 m)		Valdayan
	Grimaldian regression (down to –100 to –130 m; peak phase of the Würm Glacial)		Post-Karangatian regression (maximum at –90 m), Würm		
	Post-Tyrrhenian sea level oscillations (Neotyrrhenian, Ulja)		Regressive stages in the Karangatian sea (Surozh of the West Manych; Tarkhankut)		
Highest	Tyrrhenian transgression (Riss/Würm)	Chebba	Karangatian transgression (Riss/Würm)	Main (late) transgression phase, +5 to +7 m	Mikulino
		Main transgression phase (Rejiche, Eutyrrhenian), +5 to +7 m			
		Douira		Early Karangatian phase	
Low	Regression (Riss-II)		Post-Uzunlarian regression (Riss-II)		Moskowian
High	Paleotyrrhenian transgression		Uzunlarian transgression		Odintsovo
Low	Regression (Riss-I)		Paleoeuxinian transgression (second)		Dnieper
High	Milazzian transgression (Mindel/Riss)		Regression (Riss-I)		Likhvinian
			Paleouzunlarian transgression		
			Paleoeuxinian transgression (first)		
Very low	Extensive Roman regression (Mindel)		Extensive Venedian regréssion		Okaian
High	Sicilian transgression (warm phase, Cromerian(?))		Chaudan transgression	Epi-Chaudan phase	
				Main Chaudan phase	
Low	Early Sicilian phase			Early Chaudan phase	
	Extensive long-term regression (Günz)		Extensive long-term regression (= Tyurkyan regression in the Caspian Sea, Günz)		

lower Chaudan beds in the north of the Taman' Peninsula and lowermost strata of the Cape Chauda section). Molluscan fauna from the upper Chaudan deposits suggests the climate warming at the time of transgression maximum. Many molluscan shells of the Black Sea and Caspian origin have carbonate coating that indicates the water saturation with calcium carbonate. In the Caspian coast, the uppermost Baku beds correlative with the Chaudan level yield shells abnormally large in size, and this is also a result of warm climatic environments.

The topmost Chaudan beds bear the brackish-water cardiids and some representatives of Mediterranean fauna. Yanko (1989) reported on some planktonic foraminifers from these beds, and Chepalyga (1997) discovered *Cardium edule* at this level. The same fauna is characteristic of the upper Chaudan beds in the Caucasian coast (the Cape Idukopas and other areas). Marine fauna is known to occur in the uppermost Chaudan beds of the Mt. Tsvirmagal locality in Georgia, and also in the Gallipoli and Murefte-Chora sites near the Dardanelles.

Thus, some halophilic organisms migrated through the Bosporus Straight into the brackish-water epi-Chaudan (Karadeniz in terminology of Chepalyga) basin during the Chaudan transgression that was conditioned by the Mediterranean backwater, whose peak phase corresponded to the Sicilian transgression.

Considering geological history of the Black Sea as connected with events in the Mediterranean basin (Europe, World Ocean), we should remember that it reflects as well the Caspian Sea history and, hence, the history of basins in the vast Russian Plain and Transcaspian region. Accordingly, the Black Sea is a unique inland basin of the Earth and represents the stratotype region for Europe and western Asia.

Concluding the above considerations, I should admit that some of my statements are obvious enough, but correlation of the middle and, especially, early Pleistocene events still needs to be thoroughly studied.

The presented table illustrates my main inferences. However, I am aware that some of them are problematic like some other general assertions of stratigraphy.

Reviewer M.N. Alekseev

REFERENCES

Andrusov, N.I., *Posletretichnaya tirrenskaya terrasa v oblasti Chernogo morya. Izbr. trudy* (Post-Tertiary Tyrrhenian Terrace in the Black Sea Region. Selected Works), Moscow: Nauka, 1956, vol. 4, pp. 143–162.

Arkhangel'skii, A.D. and Strakhov, N.M., *Geologicheskoe stroenie i istoriya razvitiya Chernogo morya* (Geological Structure and History of the Black Sea Evolution), Moscow: Akad. Nauk SSSR, 1938.

Bonifay, E., Era quaternaria: definition limites et subdivisions sur la basce de la chronologie mediteterrhanee, *Bull. Soc. Geol. France*, 1975 (7), no. 3, pp. 380–393.

Chepalyga, A.L., The Detailed Event Stratigraphy of the Pleistocene of the Black Sea, *Chetvertichnaya geologiya i paleogeografiya Rossii* (The Quaternary Geology and Paleogeography of Russia), Moscow: GEOS, 1997, pp. 196–201.

Fedorov, P.V., Quaternary Stratigraphy of the Crimea–Caucasus Coast and Some Problems of Geological History of the Black Sea, *Tr. Geol. Inst. Akad. Nauk SSSR*, 1963, vol. 88, pp. 1–197.

Fedorov, P.V., *Biostratigraphy of the Quaternary Marine Deposits of the Ponto-Caspian Region. Rep. VI International Congress on Quaternary. Warsaw*, 1964, vol. II, pp. 77–88.

Fedorov, P.V., Pleistocene of the Ponto-Caspian Region, *Tr. Geol. Inst. Akad. Nauk SSSR*, 1978, issue 310.

Fedorov, P.V., The Pontian-Caspian Early Pleistocene, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 1, pp. 137–143.

Fedorov, P.V., The Pontian-Caspian Region as a Possible Stratoregion of the European Pleistocene, *Stratigr. Geol. Korrelyatsiya*, 1996, vol. 4, no. 6, pp. 99–104.

Geologicheskaya istoriya Chernogo morya po rezul'tatam glubokovodnogo bureniya (Geological History of the Black Sea Based on Deep-Sea Drilling Data), Moscow: Nauka, 1980.

Goretskii, G.I., *Allyuvial'naya letopis' velikogo Pra-Dnepra* (Alluvial Record of the Great Pra-Dnieper), Moscow: Nauka, 1970.

Keraudren, B., Les formations quaternaires marines de la Grese, *Bull. Musee Prehist. Monaco*, 1971, vols. 16, 17, p. 176.

Klige, R.K., Danilov, I.D., and Konishchev, V.N., *Istoriya gidrosfery* (History of Hydrosphere), Moscow: Nauchnyi mir, 1998.

Muratov, M.V., Quaternary History of the Black Sea Basin as Compared to History of the Mediterranean Sea, *Byul. Mosk O–va Ispyt. Prir., Otd. Geol.*, 1960, vol. 35, no. 5, pp. 107–123.

Paskoff, R. and Sanlaville, P., *Les côtes de la Tunisie variations du Niveau marin depuis le Tyrrhenian Maison de l'Orient Mediterraneen*, Lion, 1983.

Popov, G.I., *Pleistotsen Chernomorsko-Kaspiiskikh prolivov* (Pleistocene of Straits that Connected Black and Caspian Seas), Moscow: Nauka, 1983.

Svitoch, A.A., Selivanov, A.O., and Yanina, T.A., *Paleogeograficheskie sobytiya pleistotsena Ponto-Kaspiya i Sredizemnomor'ya* (Pleistocene Paleogeographic Events in the Ponto-Caspian and Mediterranean Sea Regions), Moscow: Mosk. Gos. Univ., 1998.

Vasil'ev, Yu.M., Principal Scheme of the Middle to Upper Pleistocene Stratigraphy for the Moscow Stratotype Region of Central Russia, *Chetvertichnaya geologiya i paleogeografiya Rossii* (Quaternary Geology and Paleogeography of Russia), Moscow: GEOS, 1997, pp. 40–46.

Yanko, V.V., Quaternary Foraminifers of the Ponto-Caspian Region (Classification, Ecology, Stratigraphy, and History of Evolution), *Extended Abstract of Doctoral (Geol.–Mineral.) Dissertation*, Moscow: Moscow State Univ., 1989.

Zazo, C. and Goy, J.L., Sea-Level in the Iberian Peninsula during the Last 200 000 Years: Late Quaternary Sea-Level Correlations. Applications, *NATO ASI Series*, Scott, D.B., Pirazzoli, P.A., and Honig, C.A., Eds., Dordrecht: Kluwer Acad., 1989, pp. 27–39.

Zeuner, F., *The Pleistocene Period*, London: Hutchinson, 1959.

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 498–510. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 82–95.
Original Russian Text Copyright © 2000 by Laukhin, Ronen, Ranov, Pospelova, Burdukevich, Sharonova, Volgina, Kulikov, Vlasov, Tsatskin.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

New Data on the Paleolithic Geochronology in Southern Levant

S. A. Laukhin*, A. Ronen, V. A. Ranov***, G. A. Pospelova****, Ya. M. Burdukevich*****, Z. V. Sharonova****, V. A. Volgina******, O. A. Kulikov*******, V. K. Vlasov*******, and A. Tsatskin****

* *Institute of Problems of Arctic Development, Siberian Division, Russian Academy of Sciences, p/o 2774, Tyumen', 625003 Russia*

** *Zinmann Institute of Archeology, Haifa University, Mont Carmel, Haifa, 31905 Israel*

*** *Institute of History, Archeology, and Ethnography, ul. Rudaki 33, Dushanbe, 734025 Tadjikistan*

**** *Institute of the Earth Physics, Russian Academy of Sciences, Bol'shaya Gruzinskaya ul. 10, Moscow, 123810 Russia*

***** *Wroclaw University, ul. Svska 18, Wroclaw, Poland*

****** *Institute of the Earth Cryosphere, Siberian Division, Russian Academy of Sciences, p/o 2774, Tyumen', 625003 Russia*

******* *Moscow State University, Vorob'evy gory, Moscow, 119899 Russia*

Received October 28, 1998; in final form, March 29, 1999

Abstract—Sections of some Paleolithic sites were studied. Samples from the Yiron, Tabun, Habonim, and Bizat Ruhama sections were collected for radiothermoluminescent (RTL) dating. The geological position of the sites and its influence on the section structure are discussed. Basalt from the Yiron site is dated back to 2.4–2.5 Ma using the K–Ar method. The age of rocks overlying the basalt is also determined. Red clays located 25 m below the base of the basaltic unit yield the RTL date of 2800 ± 700 ka. RTL dates for Beds C and E in the Tabun cave are concordant with age values obtained by the thermoluminescent (TL) method. This suggests that RTL dates first obtained for Beds F (480 ± 120 ka and G (610 ± 150 and 630 ± 160 ka) are close to the real ones. In the vicinity of the Habonim Kibutz, the exposed section shows that the second kurkar overlies sandstones of the third kurkar and a lentil of sediments separating sandstones of these kurkars. The boundary member between the third and second kurkars was formed approximately 160–30 ka ago. A particular attention is paid to the Bizat Ruhama site corresponding in age to the latest interval of the Matuyama Chron.

Key words: *Paleolithic, geochronology, geology, radiothermoliminescence dating, paleomagnetic study, hamra, kurkars, southern Levant*

INTRODUCTION

There are several regions on the Earth suitable not only for more or less successful correlation between Paleolithic sites, but also for solving many problems of the Quaternary stratigraphy. These regions are East Africa, China, Java, and Levant. The sites in Levant are thoroughly studied by D. Garrod, R. Neville, A. Rust, A. Marx, and many other well-known experts on the Paleolithic culture, and the extremely high level of their investigations turned this region into the standard one for other regions also hosting sites of the early and middle Paleolithic culture. Nowadays, Levant is a key region for solving many problems met in the Paleolithic investigations: it elucidates the succession of different Paleolithic cultures, and applicability of new methods to date cultural layers has been verified here.

In Russian publications, however, the problems of Paleolithic geology have been inadequately considered. While relevant data on northern Levant were considered in some publications, those on southern Levant, which hosts the important early and middle Paleolithic sites once excellently described by Korobkov (1978), did not received an attention of Russian researchers during last two decades. This particularly concerns the last decade, when the information exchange between Russian and foreign scientists became considerably reduced. Meanwhile, attempts to correlate the Levantine Paleolithic sites with the coeval sites in Siberia and Central Asia have been repeatedly undertaken (Ranov, 1988, Derevyanko and Markov, 1998; and others) and are still in progress, and the shortage of information on Levant is quite perceptible now. This paper prepared by the international scientific team is aimed to close the lacuna. Laukhin and Ranov investigated the Paleolithic geology in southern Levant during two field seasons. Ronen spent more than thirty years for the problem and headed many expeditions on the Israel territory. Other authors either participated in field geological works in southern Levant, or analyzed the materials collected in Israel. Here, we present results of two field expeditions.

During field seasons of 1995 and 1999, several Paleolithic sites of Israel were studied. In some of them, we

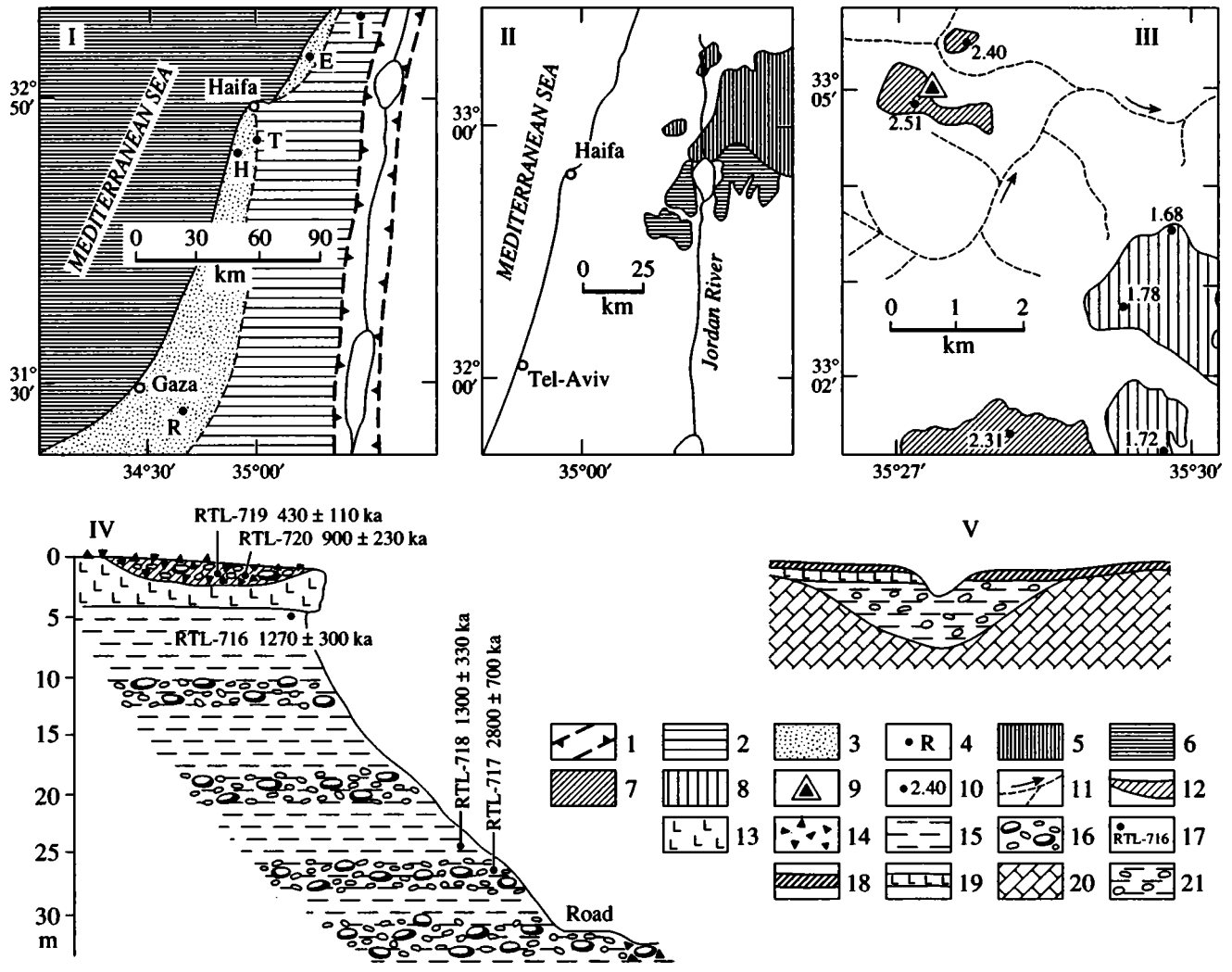


Fig. 1. Some geological features of the Paleolithic sites in Israel. (I) Area of the Bizat Ruhama site selected for paleomagnetic study: (1) rift valley of the Jordan rift; (2) rises and mountains in western flank of the Jordan rift; (3) maritime plain; (4) Paleolithic sites Yiron (Y), Evron (E), Tabun (T), Habonim (H), and Bizat Ruhama (R). (II) Distribution areas of Pliocene–Quaternary basalts older (5) and younger (6) than 4 Ma in the southern Levant (after Weinstein-Evron *et al.*, 1995). (III) The Yiron Kibutz area (after Ronen, 1991): (7) basalts 2.3–2.6 Ma old; (8) basalts 1.7–1.8 Ma old; (9) the Yiron site; (10) sampling sites and K–Ar dates, Ma; (11) wadi system. (IV) Bed sequence at the Yiron site: (12) loam, brownish to dark gray, with organic matter; (13) basalts; (14) levels of artifact finds; (15) red-colored clay; (16) sediments with boulders and pebbles; (17) sampling sites for RTL dating. (V) Relationships between Cenozoic deposits around the Yiron site: (18) loam; (19) basaltic flow; (20) Eocene carbonate rocks; (21) red-colored clay with boulder–pebble lentils.

collected samples for radiothermoluminescent (RTL) dating, and the Bizat Ruhama Paleolithic site was sampled for paleomagnetic studies (Fig. 1). The RTL dating was performed at the Laboratory of Environmental Dosimetry, Radioactivity and Radiothermoluminescent Dating of the Moscow State University (Laukhin, *et al.*, 1996; Ronen *et al.*, 1998). Samples were analyzed using the method described earlier (Vlasov and Kulikov, 1988; Kulikov and Vlasov, 1989). The analytical procedure of paleomagnetic measurements is described below in the section devoted to Quaternary geology of the Bizat Ruhama site.

GENERAL GEOLOGY OF PALEOLITHIC SITES

The geological structure of Paleolithic sites in southern Levant, in particular the abundance, composition, geological position, and preservation (and/or disturbance) of cultural layers depends, to a significant extent, on the position of sites (localities) in the Jordan rift structures representing the northern branch of the African–Arabian rift system, the largest one among systems of this kind.

The Jordan rift is a submeridional chain of grabens united into a narrow rift valley, whose bottom is located substantially below sea level and hosts several lakes

(largest among them are the Dead Sea and Lake Kennaret) connected by the Jordan River. Within the grabens, cultural layers of Paleolithic sites and host deposits are highly deformed. For instance, dip angles of cultural layers at the Ubeidya site may be as steep as 75°. We did not pay a special attention to Paleolithic sites located directly in the rift valley and do not consider their geology in detail.

The western flank of the Jordan rift experienced a relatively slow arching with local blocky uplift during the Quaternary.[1] The uplift resulted in destruction of sites exposed at the day surface causing dispersion of artifacts over large areas and their, presumably repeated redeposition. Cultural layers of some Paleolithic sites are overlain here by basalts erupted at the rifting stage. The uplift also favored formation of abundant karst caves in carbonate massifs in the western flank of the rift. Some of them host the Kebara, Shul, Tabun, and other Paleolithic cave sites known worldwide.

In the west, uplifts of the western flank of the rift are in contact with the maritime plain (Fig. 1, I), where marine sediments were deposited in the course of the Mediterranean Sea transgressions and reworked by different superimposed processes. Most effective were eolian and soil-forming processes. As a result, the maritime plain has the spur-and-groove structure. Ridges (and separating depressions) stretch parallel to the shore line of the Mediterranean Sea and are composed of sandstone with very compact carbonate matrix. Relics of shells and their fragments enclosed in sandstone indicate the rock cementation by carbonates derived from decomposed molluscan shells. The psammitic components of sandstone are of marine origin, although the rock lamination resembles that characteristic of eolian sediments. The ridges are known under local name "kurkars."

The origin of kurkars is debatable, but it is unimportant for our purpose whether they are accumulative structures of transgressions (Korobkov, 1978; Horowitz, 1979; and others) and regressions (Farrad and Ronen, 1974; and others) or represent marine coastal bars and dunes reworked by eolian processes. The important thing is that eleven kurkars in the study area (and composing sediments) become older landward. In response to neotectonic movements, kurkars converged in area northward of Haifa, where they join each other and sandstones of younger kurkars overlap deposits of older structural elements (Korobkov, 1978; Ronen, 1991). To the south of Haifa, kurkars diverge in the fan-shaped manner to became progressively distant from each other further southward. Directly south of Haifa, younger kurkars may still overlap the older ones, but this case is less frequent than in areas located north of Haifa. At the latitude of Gaza and in southerly areas, older kurkars (beginning from the eighth or ninth) are buried under younger middle pleistocene and lower Pleistocene subaqueous sediments. Locally, the section is crowned by the loess–soil formation usually dated back to the late Pleistocene (Brunis and Jaalon, 1979).

Formation of kurkars (ridges) was accompanied by accumulation of palustrine sediments in depressions between them. Stages of sedimentation and activation of eolian processes alternated with breaks in sedimentation, when ancient buried soil formed at the kurkar surface; the soil is known under the local name "hamra." The development of hamra marks termination of the kurkar formation, and ages of hamra and kurkar are closely interconnected. However, hamras are mainly preserved in the buried state. When accumulation of marshy sediments ceased with the eventual formation of the kurkar, then the same hamra overlies both the kurkar and palustrine deposits. Sometimes, the latter accumulated also during the hamra formation. The section of palustrine sediments is frequently crowned with gley soil laterally replacing the hamra, or with younger soil in case, when accumulation of marshy sediments terminated after the kurkar formation.

Artifacts are usually confined to hamra or upper layers of marshy sediments. This suggests that the periods of eolian process activation and kurkar formation were less favorable for visiting the maritime plain of southern Levant by Paleolithic humans.

DISCUSSION OF FIELD OBSERVATIONS AND ANALYTICAL RESULTS

The Yiron Site

The Yiron site is one of most excellent at the day surface of the western flank of the Jordan rift (Fig. 1). It is located in the Upper Galilee, where to the north of the Lake Kennaret, there are exposed basalts younger than 4 Ma (Weinstein-Evron *et al.*, 1995). The basalt sequence includes the small Yiron-Aviv lava sheet (Fig. 1, III) dated by the K–Ar method back to 2.4–2.5 Ma (Ronen, 1991). This sheet is cut by the Aviv Wadi into two table rises (erosion remnants). Near the Yiron Kibutz, basalts of the remnant are dated back to 2.51 Ma.

The basalts are overlain by the boulder layer with a sandy loam matrix; the apparent thickness of the layer is 1–2 m (Fig. 1, IV). Sandy loam is brownish, dark gray, intensely humified throughout its section. The loam texture is cloddy; the acute-angled clods are 2–3 mm across. The sandy loam is probably a pedosediment consisting of redeposited fossil soil, mainly of its horizon A. Boulders are small (up to 10–20 cm across) and differently, usually poorly and moderately rounded. Present are also abundant pebbles, also poorly rounded, and rock debris. Debris, pebbles, and boulders are basaltic in composition. Debris and pebbles are poorly sorted, and their intercalations have horizontal attitude. The matrix varies from basal to interstitial one. Sorting and horizontal attitude of psephite intercalations impart a slightly expressed horizontal bedding of sediments. Psephites enclose abundant Acheulian arti-

[1] The eastern flank of the Jordan rift is not considered in the paper.

facts. The latter are covered with compact ocherous orange–gray patina. Artifacts are dispersed more or less regularly, without concentration or confinement to particular levels. These artifacts were discovered 25 years ago (Gilead, 1970; Ronen *et al.*, 1974) and described many times.

Two dates obtained for the member overlying the basalt unit are equal to 430 ± 110 (RTL-19) and 900 ± 230 (RTL-720) ka (Laukhin *et al.*, 1996). The samples were collected 265 cm apart and almost at the same hypsometric level, although the older one was taken 35–40 cm above the younger. The regular distribution of organic matter, noticeable, though slightly expressed bedding, and regular distribution of artifacts throughout the section suggest in combination that both sediments and artifacts are redeposited. It seems that the younger date is close to the time of the latest redeposition episode, whereas the older one points to the time of sediment accumulation. The age of artifacts most likely falls within the interval between 430 and 900 ka.

In the same area near the Yiron Kibutz, Ronen found artifacts below the basalt sheet 2.51 Ma old (Fig. 1, III, IV), and, judging from their position under basalts, these artifacts should be older than 2.5 Ma and can be considered as the oldest finds in Eurasia. Inasmuch as artifact dating is mainly based on their position under dated basalts, let us consider the basalt sequence in more detail.

The thin (2.6–4.0 m) basalt sheet of the Yiron Kibutz area is underlain by Eocene limestone beds, which are dissected by Neogene ravines (Fig. 1-V). The ravine streams flowed westward, toward the Mediterranean Sea. Modern streams (including the Aviv Wadi) flow into the Jordan River. This suggests a significant age of ravines buried under basalts. The considered ravines are filled with red proluvial sediments (brownish red clay with rock debris). The uppermost clay layer directly under basalts is bleached by ignition to the depth of 50 cm and shows a glassy structure and columnar jointing down to 5–10 cm. The thermal alteration of red clay under basalt unequivocally indicates an older age of clays as compared with basalts.

Red clays occurring 23 m below the basalt unit enclose lentils of boulders 0.7–1.0 to 2–3 m thick. Boulders are isometric, moderately and poorly sorted, relatively small (up to 20–25 cm across); they coexists with abundant slightly rounded rock blocks (50 cm across and more). Psephites are composed of fragments of local Eocene limestones. Clay in boulder deposits is brownish red, less bright than in the host beds. Boulder deposits contain abundant pebble and debris of limestones. One of the lentils located approximately 30 m below the basalt unit turned out to be yielding artifacts (Ronen *et al.*, 1980; Brunnaker *et al.*, 1989), which were sampled many times since the discovery time (Ronen, 1991, 1996; and others) and are excluded from consideration here.

The slope composed of red clay extends down to the road, above which the clay encloses the boulder–pebble lentil observable in the road excavation (Fig. 1, IV). In 1995, Ronen studied brownish red clay of the lentil, and sampled, in addition previously known archeological finds, a new collection of artifacts.

Since the red clay enclosing lentils with boulders and artifacts is overlain by basalts, the clay and artifacts cannot be younger than 2.51 Ma. To clarify the age of clay and artifacts, Laukhin and Ronen collected, during the field work of 1995, three samples for the RTL dating: one sample from the roof of the clay member and the other two from the level directly above the artifact finds (Fig. 1, IV). Two samples, one from the roof level (clays ignited by basalts) and another from clay of the lentil with boulders (the depth of 23.7 m below the base of the basalt sheet), yielded comparable age values of 1270 ± 300 (RTL-716) and 1300 ± 330 (RTL-718) ka, which are obviously rejuvenated being significantly younger than the basalt overlying the clay member. Only one sample taken from the lentil at the depth of 25 m yielded the value of 2800 ± 700 ka (RTL-717), which may illustrate the real age of red clay. Buried ravines were filled with proluvial sediments very rapidly, because signs of sedimentation breaks or changes in lithology have not been observed in the interval of 30 m below the basalt unit. Therefore, the artifacts can be considered as close in age to the date RTL-717.

The dates obtained for red clays above the depth level of 25 m are rejuvenated under influence of some physical factors. This issue is an object for discussion of physicists, the experts in isotopic and radiothermoluminescent methods, and we do not consider it here.

The Tabun Site

Cave deposits at the western flank of the Jordan rift were dated using samples from the Tabun Cave site at the western scarp of the Carmel Plateau (Figs. 1, I, 2).

The Paleolithic deposits of the Tabun Cave are discussed in many publications. Their sequence is described in detail in several works (Garrod and Bata, 1937; Jelinek, 1973; Korobkov, 1978; Ronen, 1996), and all these descriptions are well compatible. Here, we accept the description by Garrod and Bata, who defined the succession of beds A–G (Fig. 2), of which beds C–D correspond to the Mousterian, Bed E is correlated with the Acheulian–Yabrudian, beds F and G with the Acheulian, and the basal part of Bed G with the Taycian. Beds B–E are characterized by many dates, whereas beds F and G had no dates until recently. Dates available for beds B–E slightly differ in different publications. In addition, different methods provide substantially different age estimates: EPR dates appear to be significantly younger as compared with those obtained by the thermoluminescent (TL) dating. The discordance is systematic; the older are deposits the greater is the age difference, and all these aspects of the problem

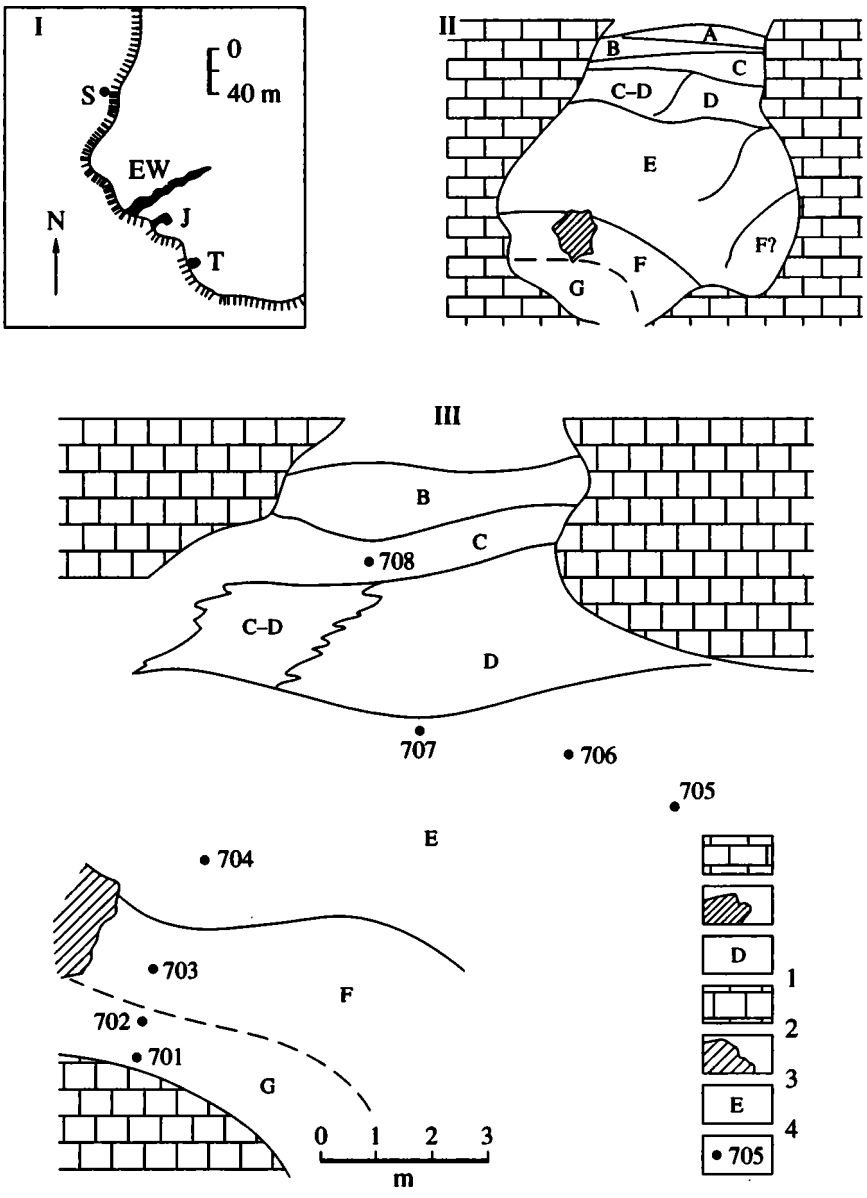


Fig. 2. The Tabun Cave area (I) at the western slope of the Carmel Plateau (after Ronen, 1996), where the cave sites Shul (S), El-Wadi (EW), Jamal (J), and Tabun (T) are located. The Tabun Cave section (II) and sampling sites for RTL dating (III): (1–3) for II: (1) carbonate rocks; (2) cavern; (3) bed indices (after Garrod and Bate, 1937); (4–7) for III: (4) carbonate rocks; (5) cavern; (6) bed indices (after Garrod and Bate, 1937); (7) sample numbers used for RTL dating. List of dates obtained: RTL-701, 630 ± 160 ka; RTL-702, 610 ± 150 ka; RTL-703, 480 ± 120 ka; RTL-704, 410 ± 110 ka; RTL-705, 340 ± 80 ka; RTL-706, 260 ± 60 ka; RTL-707, 270 ± 60 ka; RTL-708, 108 ± 27 ka.

were repeatedly discussed (Bar-Yosef, 1992a, 1992b, 1995a, 1995b; Bar-Yosef and Meignen, 1992; Mercier *et al.*, 1995; and others). We were first to sample beds G and F for the RTL dating; samples were taken from areas, where these beds are virtually undeformed. For comparison with previous TL dates, samples were taken also from clayey Bed C and from different levels of sandy Bed E (Fig. 2). The recently obtained TL dates for Beds C–E (Bar-Yosef, 1995; Mercier *et al.*, 1995) were also used for comparison (Table 1).

The RTL dates determined for beds C and E are concordant with those obtained by the TL method. Thus, the dates first determined for beds F and G can be considered as correct. They also do not contradict determination of the Acheulian and Taycian artifacts from these beds.

The Habonim Section

In the Haifa area, the Carmel Plateau reaches the sea and divides the maritime plain into two parts. In its

southern part, kurkars diverge in the fan-shaped manner southward, although there is some overlapping of older kurkars by younger ones in the northernmost part of this area. In the vicinity of the Habonim Kibutz situated 20–22 km southward of Haifa (Fig. 1, I), a quarry section demonstrates that the second kurkar overlies sandstones of the third kurkar and a lentil of palustrine sediments separating these two sandstone units. The Habonim section was never described in publications, and its description is presented below for the first time.

Three members are distinguished in the Habonim section (from the top downward; see Fig. 3).

(1) The upper sandstone member corresponding to the second kurkar is light–gray to white, very compact, calcareous, variably grained (coarse-grained to gravelly), displaying the diagonal and oblique bedding. The base bed (10–20 cm thick) of the member consists of loose sandstone (poorly cemented sand). The member thickness is 10–15 m.

(2) The middle member is represented by palustrine sediments 4.6 m thick, grading into hamra (0.3–0.5 to 1 m) along the strike. The uppermost part of the member corresponds to dark–gray very compact gley soil. In the lithological aspect, the soil is loamy, with crystalline carbonate "columns" up to 10–15 cm long and 2–3 cm across. Predominantly greenish and bluish coloration is characteristic of ferrous oxides. The bed of gley soil is 1–1.2 m thick. The 1.5-m-thick middle part of the member is composed of grayish brown compact loam showing signs of soil-formation. The lower part corresponding to hamra is composed of red sandy clay (1.9 m). The lentil comprising the upper and middle parts of the member rest on the lower hamra layer traceable throughout the entire exposure significantly decreasing in thickness beyond the lentil.

(3) The lower member corresponds to the buried kurkar and is composed of compact bedded sandstone. Its apparent thickness is 4 m.

The total thickness of the Habonim section is about 25 m. We studied in detail its lower 7-m-thick interval spanning sandstone of the upper member, marshy clays, hamra, and the uppermost part of sandstone representing the third (buried) kurkar.

At the Habonim site, rare Mousterian artifacts are recovered from the gley soil at the roof of marshy sediments and from hamra layer beyond the lentil.[2] Artifacts are usually small. This and their wide dispersion suggest that no massive tools were required for waterfowl hunt in boggy marsh coasts unfavorable even for temporal sites. Data on the Habonim section show that palustrine sedimentation commenced after the hamra formation and buried this layer in the marshy depression. The erosional contact between hamra and overlying palustrine sediments is absent, nonetheless, the distinct hamra surface suggests an insignificant break in sedimentation between the termination of soil-forming processes and penetration of marshy waters into depression. Beyond the marshy depression, more than a half of the hamra section was eroded from the slopes of buried kurkar at the time of sedimentation break. It follows that accumulation of palustrine sediments of the Habonim section occurred after this break (the hamra formation time) and directly preceded accumulation of sands in the second kurkar. In other words, it was an onset of the sedimentation cycle that produced the second kurkar.

Comparison of thermoluminescent dates (ka) obtained for Beds C–E (after Bar-Yosef, 1995, Mercier *et al.*, 1995) and radiothermoluminescent dates obtained by Vlasov and Kulikov for our samples (Laukhin *et al.*, 1996)

Bed	TL dates after Bar-Yosef, 1995*	TL dates after Mercier *et al.*, 1995*	RTL dates
C	105–195	150–185	108 ± 27
C/D	–	190–270	–
D	190–260	235–290	–
D/E	–	240–290	–
E	up to 350 and older	240–385	260 ± 60, 270 ± 60
			340–80, 410 ± 110
F	–		480 ± 120
G	–		610 ± 150, 630 ± 160

* Average values for published date series.

Several RTL dates were obtained for different levels of the Habonim section: 30 ± 7 ka (RTL-712) for the upper sandstone bed (sample taken 80 cm above its base); 45 ± 10 ka (RTL-711) for gley soil in the upper part of the palustrine lentil (the level of 109 cm below the base of the upper sandstone member); 90 ± 20 ka (RTL-709) for loam from the lentil (the level of 2 m below the base of the upper sandstone member); 130 ± 33 (RTL-712), 107 ± 27 (RTL-722) and 160 ± 40 (RTL-710) ka for hamra (the levels of 4.25 m below the base of the upper sandstone member, of 1.3 m below the roof of the lower sandstone member, and of 3.3 m below the roof the latter, respectively). The regular age succession is violated only by the date RTL-722 obtained for the sample presumably taken with an insufficient penetration into the wall of exposed rocks. This irregularity cannot, however, call into question all other dates. If the date succession is true, we may interpret the history (and mechanism) of kurkar formation otherwise than it is commonly accepted. The standard viewpoint (Korobkov, 1979; Horowitz; and others) is that the hamra–kurkar cycle corresponds to the climatic glacial–interglacial or regressive–transgressive cycle.

The RTL dates obtained for the Habonim section show that the sedimentation cycle corresponding to the

[2] When this paper was in press, two articles were published (Ronen *et al.*, 1999; Tsatskin and Ronen, 1999); the authors discussed in detail the composition and genesis of soil and artifacts from the Habonim section, the results of the field work of 1996, included.

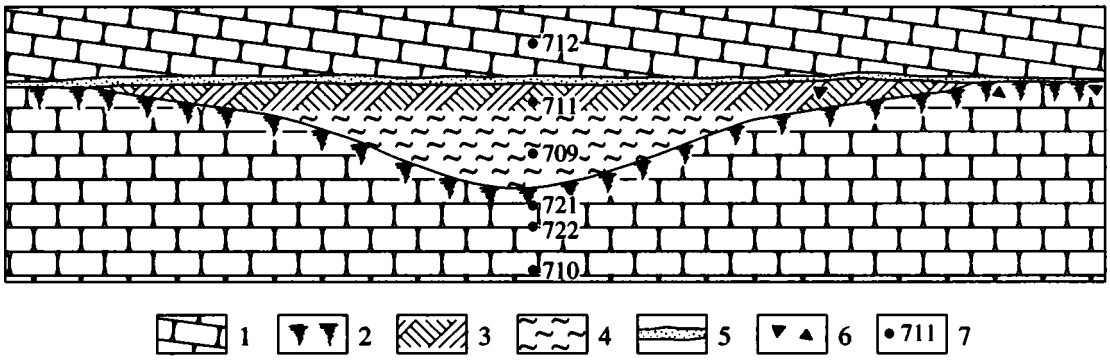


Fig. 3. The structure of the Habonim section.

(1) Kurkar sands; (2) hamra; (3) gley soil at the roof of marshy sediments; (4) marshy loam; (5) interbed of poorly cemented sand at the base of the upper kurkar; (6) artifact location; (7) sample numbers used for RTL dating. List of dates obtained: RTL-712, 30 ± 7 ka; RTL-711, 45 ± 10 ka; RTL-709, 90 ± 20 ka; RTL-721, 130 ± 33 ka; RTL-722, 107 ± 27 ka; RTL-710, 160 ± 40 ka.

second kurkar formation spans the early and middle Wurm. Moreover, the kurkar proper was formed in the middle Wurm, the peak of which coincides with the gley soil formation on palustrine sediments and, probably, on the lower hamra horizon preserved from erosion at the surface of the buried kurkar beyond the area of palustrine sedimentation. The Riss–Wurm corresponds to formation of thick soil, which is (completely ?) preserved only under marshy sediments. The fairly old date of 160 ± 40 ka (RTL-710) obtained for the upper part of the buried kurkar suggests that the latter was also formed in the middle (not late) Riss. We do not tend to revise, based on the dates obtained from a single section, the existing interpretation of the history of the Levantine maritime plain. Nonetheless, the above-mentioned facts arouse interest in additional serial dating of other kurkar sections, particularly of their levels corresponding to marshy sediments of a significant thickness. As for dates obtained for the marshy lentil in the Habonim section, it is desirable to test them conducting the detailed paleomagnetic study particularly taking into consideration that the section structure is suitable for the sample-by-sample examination.

The Bizat Ruhama Section

In the area located approximately 28 km east of Gaza in the southern part of the maritime plain, where kurkars are buried and morphologically unexpressed, we studied the Quaternary section at the Bizat Ruhama site (Fig. 1, I). This site was discovered in 1996 (Ronen *et al.*, 1998). The study of Quaternary deposits at the site was started during the field work of 1995 and continued in 1996. A particular attention was paid during both field seasons to the geological situation in the area, and geological features of the site are considered here in more detail as compared with other sites.

The Bizat Ruhama site has a peculiar geomorphological position. At the distance of 2.5 km to the northeast of the Ruhama Kibutz, a small (3–5 km across) area of badlands opens southward in the form of the amphitheater. In its eastern part, there is a ravine 72–75 m long, 16–18 m deep and stretching in submeridional direction to join the sublatitudinal (WNW–ESE) depression. The eastern wall of the ravine is about 6 m high (altitude about 100–100.5 m), whereas the western one is up to 17 m high (altitude 111 m). The fosse across the Bizat Ruhama site is located at the base of western wall (altitude interval of 95.5–96.5 m) in the middle part of the ravine. The most complete section was studied along the western slope of the ravine. For this purpose, three fosses in the lower part of the slope in the altitude interval of 96.5–102.5 m, as well as several shallow excavations were made across the slope. The photograph of the excavation area was published by Laukhin *et al.* (1998).

The fosse and several other excavations in the eastern wall of the ravine revealed that the section is similar in structure on both slopes and shows only small variations in the layer thickness and position of contacts between layers.

Several layers are distinguished in the Bizat Ruhama section from the top downward (Fig. 4).

(1) Bed 1 of sandy to light loam, beige–gray with the brownish shading; the rock is loess-like, highly porous, massive, and calcareous. Its grumous structure in the upper part of the member grades downward to finely detrital. Brown coloration becomes more distinct in the same direction. The $CaCO_3$ content is uniform in general, but there is a level located 0.7–0.8 m down the section, where carbonates are concentrated in the form of small white points and isometric spots (0.2–1.2 cm across). The rock shows the vague columnar jointing. The contact between beds 1 and 2 is locally abrupt, of the erosional type, marked by pebbles dispersed along the erosion surface; in other places, the transition is gradual. The bed thickness is 1.0–1.5 m.

Abundant artifacts from Bed 1 are of the Mousterian (in the lower part of bed 1and in talus covering the upper part of Bed 2) and Epipaleolithic cultures.

(2) Bed 2 of chocolate–brown loam with slight reddish shading in the lower part; the rock is clayey (sand grains are variably rounded) to silty, massive, very sticky, and coarse-detrital. Clasts are acute-angled, 5–12 cm long, and displaying the columnar jointing; on the slope, they are dispersed as small angular fragments. Facets of large fresh fragments are covered by black (manganese?) film; some oblique (30°–50°) facets of fragments, particularly from the lower half of the bed, show slickensides. Distinct fractures responsible for appearance of slickensides have not been observed. Manganese(?) films are also seen in horizontal fucoids about 5 mm in diameter.

Large white calcareous spots (2–7 cm across) and carbonate concretions usually flat in shape and up to 1–2 × 10–12 cm in size are irregularly distributed throughout the bed. Frequently, concretions form lenticular accumulations (20–60 m thick) along vertical fractures or located perpendicular relative to the latter (in a horizontal position). Areas of Bed 2 impoverished in the carbonate material are about 50 cm across. We failed to observe horizons of carbonate spots in fosses. Horizontal whitish (calcareous?) bands 1 m wide and more are visible within Bed 2 in dried walls of the ravine. The number of bands and their width vary with time being likely dependent on the wall dryness extent.

Talus covering Bed 2 includes pebbles and small-sized boulders. We did not observe this material in Bed 2 proper, probably, because of its scarcity. It is not inconceivable that the pebbly material could have been brought by humans. In the lower part of Bed 2, loam is massive. The columnar jointing is observable down to the depth of 10 m from the bed roof. The contact between Beds 2 and 3 appears to be gradual. The lower part of Bed 2 corresponds to the transitional member 40–50 m thick, where loam first turns into grayish and then, losing brown coloration, grades into the black clay of Bed 3. This transitional member is observed in both walls of the ravine. The total thickness of Bed 2 (together with transitional member) is 11–12 m.

Although small-sized artifacts are sufficiently abundant in the talus covering Bed 2, they have not been discovered inside this bed.

(3) Bed 3 of black to grayish black clay that becomes ashy gray in the dry state; the clay is sandy, very sticky, highly gleyed, and massive. The content of silt fraction is low, and carbonate concretions are rare. In the shape, Bed 3 corresponds to a lentil 1.0–1.3 m thick (Fig. 4). Its exact dimensions are undeterminable. According to field measurements in isolated exposures in different ravines, the lentil is about 100–110 m long and 40–45 m wide.

Dumps of black clay contain abundant small-sized artifacts but none of *in situ* finds was registered.

(4) Bed 4 of gray to yellowish gray fine-grained sand with slightly expressed horizontal bedding; the sandy fraction is poorly rounded. The rock has a high clay content and includes dispersed black plant detritus. Horizontal intercalations of rare and small (1.5–2.0 cm) pebbles occur throughout the entire bed section. In the lower part of the bed, there are black manganese (?) concretions (0.2–1.5 rarely up to 3–5 cm across). In the lower 12–15 cm of the bed, sand is var-

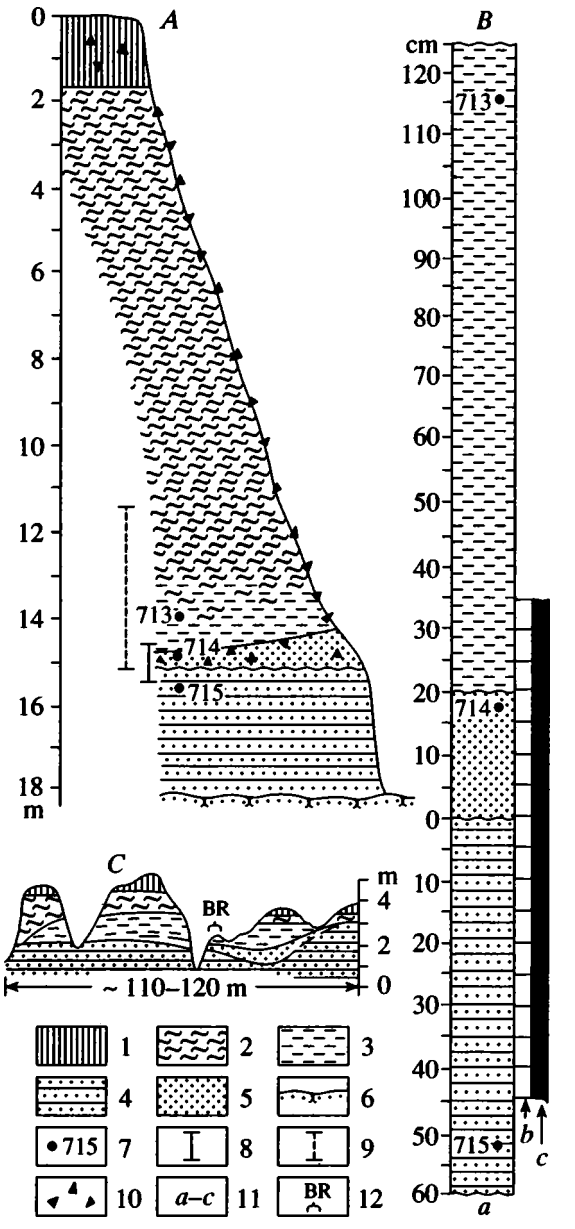


Fig. 4. The Bizat Ruhama site section (*A*), sampling points of 1995 for paleomagnetic studies (*B*), and relationships between beds of the site (*C*): (1) loess-like sandy loam; (2) brownish loam; (3) black clay; (4) red-colored sandy clay interpreted as fossil soil (hamra); (5) sand; (6) calcareous sandstone at the kurkar roof; (7) sampling points for RTL dating and numbers of samples; (8) interval sampled for paleomagnetic studies in 1995; (9) interval sampled in 1996; (10) artifacts; (11) fosse section of 1995 (*a*), sampling points of 1995 for paleomagnetic studies (*b*), and interval of the reversed polarity (*c*) according to data of 1995; (12) location of the Bizat Ruhama site in the excavation.

iegated, displaying bluish gray, greenish gray, and brownish red spots in the brownish gray ground mass. Boundaries of spots are obscure and their configuration is intricate. Locally, there are small (1.5–3 cm) elongated inclusions of red clay similar to that of Bed 5. Contacts of these inclusions are also blurred, indistinct. Black manganese(?) concretions occur mainly in the upper, variegated part of the bed (12–17 cm above its base). These horizontally oriented concretions are concentrated in subhorizontal interlayers.

Dispersed artifacts of the bed are also horizontally oriented. Some artifacts from Bed 4 are redeposited and embedded into Bed 5. Excavation works at the Bizat Ruhama site were conducted in the area, where Bed 4 is reduced in thickness to 0.2 m and has an increased abundance of artifacts.

Erosional boundaries of the bed are sharp. The bed thickness is 0.2–0.92 m.

(5) Bed 5 is composed of sandy clay; the rock is ocherous, rusty reddish grading to orange–red, massive, and very sticky. The roof of Bed 5 is covered by the thin ferruginous crust, under which the iron content gradually decreases downward to the depth of 10–12 cm. Walls of abundant fractures are covered by the rusty black film down to the depth of 12 cm. Below the level of 25–30 cm, clay encloses irregular, frequently isometric nodules (2–5 cm across) composed of pinkish white carbonate; downward, they become larger (up to 10 cm) and horizontally oriented. Below the depth of 1.5–2.0 cm, nodules are up to 25 cm across and columnar in shape. The bed thickness is 2–4 m.

(6) Bed 6 of light gray compact sandstone composing kurkar. The kurkar top is visible only in areas of the maximum incised ravine talweg. The visible thickness is several centimeters.

It is unclear which of kurkars is exemplified by sandstones of Bed 6, and this point can be clarified after study of a wider area. Correspondingly, the hamra (Bed 5) covering this kurkar is also of unclear age. Clayey sand of Bed 4 accumulated most likely in the coastal zone of a lake, as it is evident from rare pebbles and plant remains present in the bed, as well as from sand bedding and position of artifacts in the bed. Bed 3 is composed of palustrine clay. Gleyed palustrine clay of Bed 3 grades into loam of Bed 2. Bed 2 of the least clear genesis is most likely a subaqueous accumulation. Bed 1 is polygenetic, having, to a significant extent, the eolian origin and simultaneously affected by diluvial processes.

Since the 1960s, the Bizat Ruhama section is known to contain Acheulian artifacts found around foothills of the badlands (Horowitz, 1979; Ronen *et al.*, 1998). Artifacts occur in the talus and *in situ*, however their confinement to a particular bed in the section remained unclear. Until recently, these finds rarely mentioned in publications were referred (Bar-Yosef, 1994), on the basis of data published almost 20 years ago, to the middle Acheulian culture, whose oldest facies were considered by Bar-Yosef as corresponding to either the Brunhes–Matuyama transition, or the latest episode of the Matuyama Chron. In 1995, we discovered several *in situ* Acheulian artifacts in Bed 4 of the Bizat Ruhama site, and their excavation was continued by the Polish–Israel expedition under leadership of Ronen and Burdukevich in 1996 (Ronen *et al.*, 1998). Bed 1 was discovered to contain separate Epipaleolithic artifacts. These and Mousterian artifacts occur in abundance throughout the entire Bed 2 exposed at the slope. The exact confinement of the Mousterian artifacts (to the base of Bed 1 or to Bed 2) is unclear. In any case, it seems that they are missing from Bed 2, but this must be verified. Remains of large mammals sampled around the Bizat Ruhama site are rare, poorly preserved, and unsuitable for age determination. Any other fossils from this area are unknown. We used physical, paleomagnetic and RTL methods to date the Bizat Ruhama section. It was also taken into consideration that the loess–soil sequence in its stratotype area between Ruhama and Dorot (5–7 km westward of the Ruhama site) is underlain by the Dorot hamra, which is dated back to the Mindel (Horowitz, 1979). The location of the considered section at some distance from the stratotype allows an assumption that the hamra (Bed 5) and interrelated kurkar were formed prior to the Mindel.

In 1995, samples for RTL dating were selected from Beds 2 (near the transition to Bed 3), 4, and 5; the respective sampling levels are 115 cm (RTL-713, 480 ± 120 ka) and 18 cm (RTL-714, 740 ± 180 ka) above the roof of Bed 5 (hamra), and also inside the hamra bed 54 cm below its roof (RTL-715, 840 ± 200 ka). A significant time interval (360–440 k.y.) characterizing accumulation of the relatively thin (169 cm) sequence appears to be a consequence of two breaks in sedimentation recorded at the base and roof of Bed 4, when some sediments could have been eroded. The normal stratigraphic succession of the dates obtained suggests a systematic measurement error, if there is some. In case of an error, the RTL dating (Vlasov and Kulikov, 1989) implies a younger, but not older age of the analyzed rocks. In fact, the paleomagnetic study of samples taken from the narrower interval of the same fosse (Fig. 4) showed them to be of reversed polarity zone.

PALEOMAGNETIC AGE OF THE BIZAT RUHAMA SITE

First paleomagnetic study of rocks from the Bizat Ruhama section performed by V.V. Semenov (Institute of Geography RAS) revealed the reversed magnetization of samples taken at 17 levels in the upper part of Bed 5, Bed 4, and in the lower part of Bed 3. It follows that rocks of these beds were formed during the Matuyama Chron (Ronen *et al.*, 1998). To specify age of the cultural horizon, paleomagnetic measurements were carried out for samples collected from Beds 4, 3, and 2 in 1996. This collection was analyzed by G.A. Sharonova and Z.V. Pospelova at the Joint Insti-

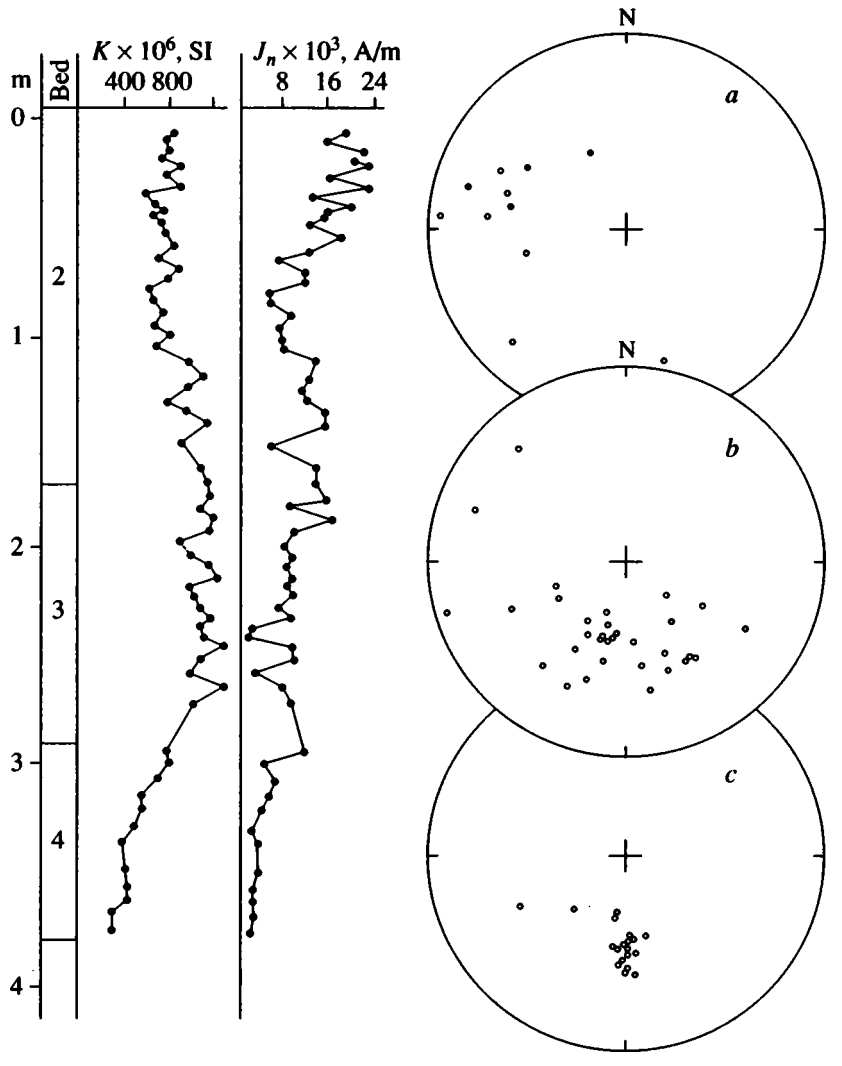


Fig. 5. Magnetic and paleomagnetic characteristics of rocks from the Bizat Ruhama section: (K) magnetic susceptibility; (J_n) natural remanent magnetization. Stereograms of J_n vectors based on the results of the J_n component analysis after step-by-step thermal demagnetization under zero magnetic field and in the temperature range from 150 to 600°C: (*a*) for the upper part of Bed 2, (*b*) for the middle part of Bed 2, and (*c*) for Bed 4. Solid and open circles designate projection of the J_n vector on the lower and upper hemispheres, respectively.

tute of the Earth Physics, Russian Academy of Sciences.

Rock samples oriented relative to the magnetic meridian were collected from two fosses located 12 m apart. Bed 4 was sampled in fosse III, where its thickness is 92 cm (by 72 cm higher than that in the main excavation area sampled in 1995). Beds 3 and 2 were sampled in the latter upward the section. As a result, a series of 189 cubic samples with an edge of 2 cm was obtained from 63 levels. It was assumed that Bed 2 corresponds to the lower part of the Brunhes Chron, or at least, to the level of its transition to the Matuyama Chron.

The magnetic susceptibility (K) of rocks was measured using the magnetometer KLY-2. The K values vary from 230×10^6 to 1230×10^6 SI (Fig. 5). The lowest of them ($230–700 \times 10^6$ SI) is characteristic of clayey sand from Bed 4. Measurements of remnant magnetization (J_n) were conducted using the system IR-4. The J_n values range from $0.8–26 \times 10^3$ to 26×10^3 A/m, and elevated values are peculiar of samples from the upper part of the section; $J_{ncp} = 19 \times 10^3$ A/m. The J_n and K values show no correlation throughout the section.

Based on the curves of saturation magnetization dependence $J_{rs}(t)$ on the temperature, it is established that main magnetic minerals in rocks are represented by magnetite, maghemite, and goethite; present in insignificant amount is also hematite, which is identified only in case of twenty-fold exaggerated scale of the high-temperature segment of $J_{rs}(t)$ curves. The $J_{rs}(t)$

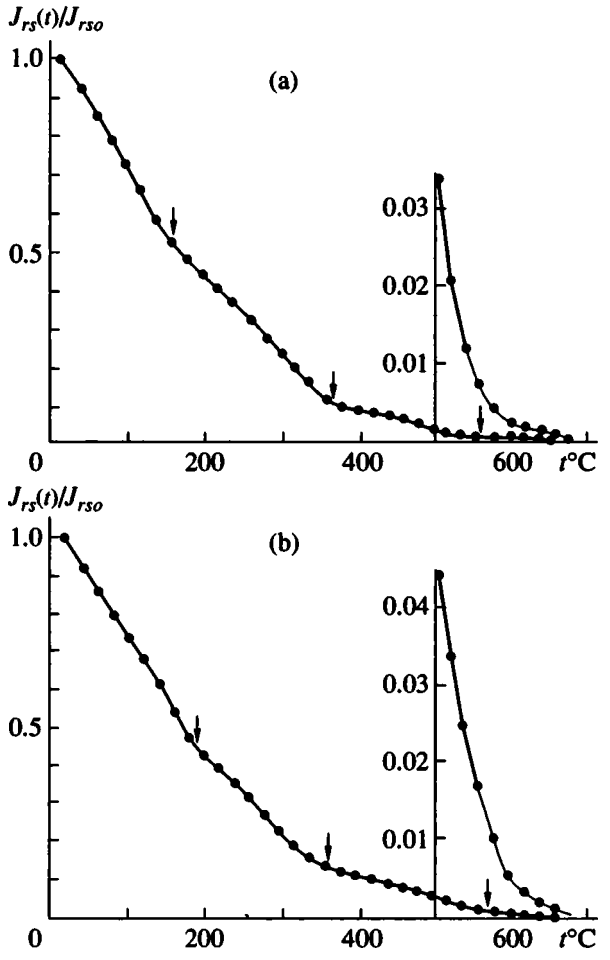


Fig. 6. Temperature curves $J_{rs}(t)$: (a) Sample 10 from the anomalous zone, (b) Sample 51 from the reversed-polarity zone. Arrows designate blocking temperatures. The $J_{rs}(t)$ curve intervals above temperature of 500°C are of the exaggerated scale.

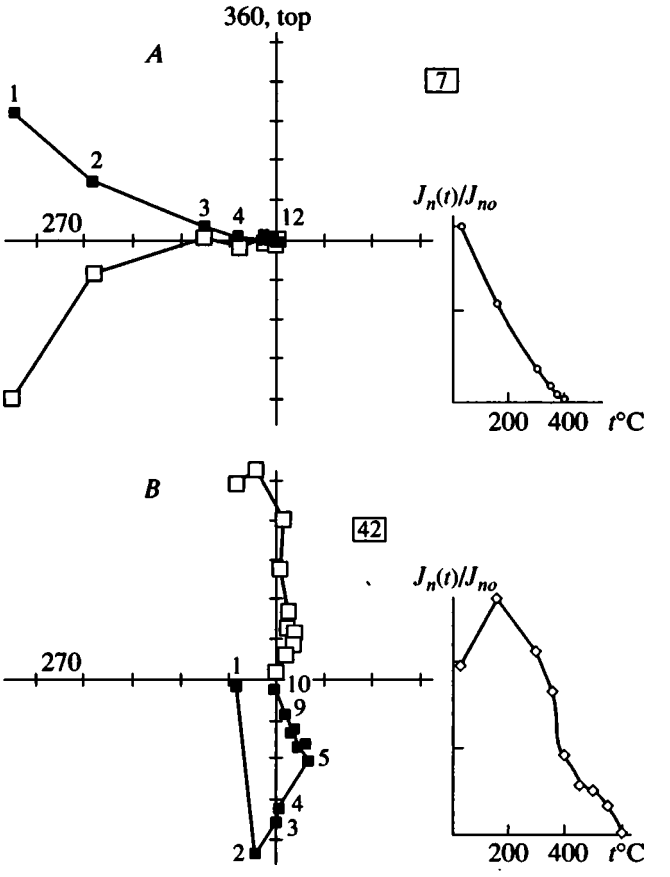


Fig. 7. The Zijderveld diagrams and $J_n(t)$ curves for Sample 7 from the anomalous zone (*A*) and for Sample 42 from the normal polarity zone (*B*): (1) 20°C, (2) 150°C, (3) 200°C, (4) 300°C, (5) 350°C, (9) 500°C, (10) 550°C, (12) 600°C. Solid and open squares correspond to projections of Jn vectors on XY and YZ planes.

curves are similar for samples from different levels of the section, although the magnetite content in samples from its upper part is substantially lower.

The component analysis of J_n values, which were measured in 12 rocks samples from different part of the section after their thermal step-by-step demagnetization in the temperature interval from 150 to 600°C and under the zero magnetic field, revealed that characteristic magnetization is determinable in the interval of 300–600°C. Therefore, remaining samples were heated to the temperature of 300, 400, 450, and 600°C under the zero magnetic field. Using Zijderveld plots, vectors of characteristic magnetization considered as representing the initial J_n direction were determined (Fig. 7). The upper 0.5-m-thick part of the section shows anomalous variations of J_n parameters: alternation of J_n with the positive and negative inclination and a high scatter of declination. The rest of the section is characterized by the reversed polarity (Fig. 5).

Based on the paleomagnetic data obtained, the upper part of the section could be interpreted as corresponding to the transition between the Matuyama and Brunhes chrons. If this is correct, the site should be referred to the upper part of the Matuyama Chron and considered as significantly younger than the Jaramillo event and Kamikatsura excursion (> 0.78 < 0.85 Ma according to Harland *et al.*, 1990). Nonetheless, such interpretation appears to be invalid because of the following reasons.

(1) Interval with the normal magnetization polarity has not been observed in the upper part of the section.

(2) Estimation of the relative geomagnetic field strength for Bed 2 of the Bizat Ruhama section using the Kenigsberger factor $Q_{n_{400}} = J_{n_{400}}/K$, where K is the laboratory field and $J_{n_{400}}$ is remanent magnetization after thermal demagnetization, showed that $Q_{n_{400}}$ values vary from 0.02 to 0.01. No decrease in the geomagnetic field strength was observed in the upper part of

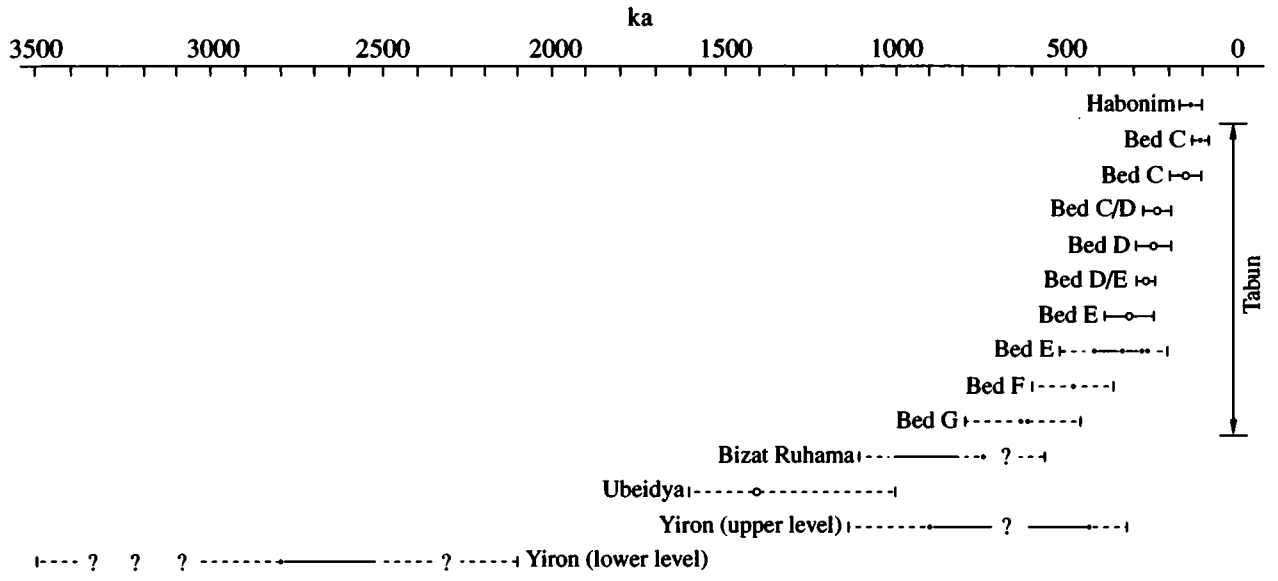


Fig. 8. Geochronological succession of Paleolithic sites mentioned in the paper. Solid and open circles designate the newly obtained and previously published dates, respectively (references are given in the text).

Bed 2, and this excludes a possibility that the transitional polarity zone is recorded in the section, because the transitional period should be accompanied by the fall of the geomagnetic field strength by a factor of 5–7 as compared with its values during the steady-state period (Petrova *et al.*, 1992).

(3) Demagnetizing samples from the upper part of Bed 2, we failed to reveal completely the primary J_n component. In the upper part of the section corresponding to the anomalous zone, the fosse was shallower that in the remainder of the section. Samples collected from the shallow fosse are more weathered than those from the deeper one, and their alteration significantly influences the J_n direction (*Metody...*, 1973). This is also evident from comparison of $J_n(t)$ curves characterizing rocks from the upper and remaining parts of the section (Fig. 6) The $J_n(t)$ curves show, as a rule, two main phases: one of maghemite disappearing under the temperature of 400°C and another of magnetite having the Curie point of 575°C. The contribution of goethite and hematite to the $J_n(t)$ values is insignificant. Magnetite is responsible for the primary reversed magnetization, whereas maghemite is secondary mineral characterized by the normal polarity. Judging form the $J_n(t)$ curves, magnetite contributes 40–50% to the J_n values in most of the samples from the section, and thermal demagnetization reveals the reversed magnetization parameters of this mineral. In the upper part of the section, abundance of magnetite substantially decreases sometimes to its complete disappearance. The thermal demagnetization reveals an integral J_n direction induced by magnetite and maghemite. It follows that the J_n direction in rocks from the upper part of Bed 2 was changed by secondary processes, and the primary one corresponds here to the Matuyama Chron.

At the present state of our knowledge, it should be concluded that all the studied rocks of the Bizat Ruhama section correspond in age to the Matuyama Chron. Inasmuch as records of the Matuyama–Brunhes transition, Jaramillo Subchron, and geomagnetic excursions have not been observed in the section, it can be assumed that rocks were formed in the time interval of 140 k.y. between the Jaramillo Subchron and Kamikatsura Event (0.99–0.85 Ma ago). Bed 4 bearing artifacts accumulated directly after the Jaramillo Subchron spanning the hiatus between Beds 5 and 4. To estimate more precisely the cultural horizon age, it is necessary to perform paleomagnetic measurements for samples collected above the Matuyama–Brunhes transition.

CONCLUSION

Summarizing available geochronological data, we may conclude that the studied section of southern Levant spans almost the entire Pleistocene and partly the Pliocene (Fig. 7).

ACKNOWLEDGMENTS

The work was supported by the INQUA Executive Committee, Haifa University, Zinmann Institute of Archeology, and by the Russian Foundation for Basic Research, project nos. 97-06-80129 and 98-05-64691.

Reviewers M.A. Akhmet'ev,
Yu.B. Gladenkov, and E.V. Devyatkin

REFERENCES

Bar-Yosef, O., Middle Paleolithic Human Adaptation in the Mediterranean Levant, *The Evolution and Dispersal of Modern Humans in Asia*, Hokusen-Sha, 1992a, pp. 189–215.

Bar-Yosef, O., The Role of Western Asia in Modern Human Origins, *Philos. Trans. R. Soc. London*, 1992b, no. 337, pp. 193–200.

Bar-Yosef, O., The Lower Paleolithic of the Near East, *J. World Prehistory*, 1994, vol. 8, no. 3, pp. 211–265.

Bar-Yosef, O., The Origin of Modern Human, in *The Archaeology of Society in the Holy Land*, London: Leicester Univ., 1995a, pp. 110–123.

Bar-Yosef, O., The Lower and Middle Paleolithic in Mediterranean Levant: Chronology and Cultural Entites, *Man and Environment in the Paleolithic*, Leige: ERAUL., 1995b, no. 62, pp. 247–263.

Bar-Yosef, O. and Meignen, L., Insights into Levantine Middle Paleolithic Cultural Variability, in *The Middle Paleolithic,: Adaptation, Behavior and Variability*, Univ. Museum Monographs, vol. 78, Univ. of Pensylvania, 1992, pp. 165–182.

Brunis, H.J. and Yaalon, D.H., Stratigraphy of the Netivot Section in the Desert Loess of the Negev (Israel), *Acta Geol. Acad. Sci. Hung.*, 1979, vol. 22, nos. 1–4, pp. 161–169.

Brunnaker, K., Boenigk, W., Bruder, G., *et al.*, Artefacte im Altquartar von Oberg Alilaa (Nordisrael), *Eiszeitalter und Gegenwart*, 1989, no. 39, pp. 109–120.

Derevyanko, A.P. and Markov, S.V., The Mousterian of the Southern Part of Northern Asia as Compared with the Middle Paleolithic of the Eastern Mediterranean, in *Paleoekologiya pleistotsena i kul'tury kamennogo veka Severnoi Azii i sopredel'nykh territorii* (Pleistocene Paleoecology and Stone Age Culture of Northern Asia and Adjacent Areas), Novosibirsk: IAE SO RAN, 1998, vol. 1, pp. 100–106.

Farrad, W.R. and Ronen, A., *Observation on the Kurkar-Hamra Succession on the Carmel Coastal Plain, Israel*, Tel-Aviv, 1974, no. 1, pp. 45–55.

Garrod, D.A. and Bate, D.M.A., *The Stone Age of the Mont Carmel: Excavations of the Wadi-el-Mughara*, Oxford, 1937.

Gilead, D., Handaxe Industries in Israel and the Near East, *World Archaeol.*, 1970, vol. 2, pp. 1–11.

Harland, W.B., Armstrong, R.L., Cox, A., *et al.*, *A Geological Time Scale*, Cambridge: Cambridge Univ., 1990.

Horowitz, A., *The Quaternary of Israel*, New York: Academic, 1979.

Jelinek, A., Farrad, N.R., Haas, G., *et al.*, New Excavation at the Tabun Cave (Mont Carmel, Israel). Preliminary Report, *Paleorient.*, 1973, no. 1, pp. 151–183.

Korobkov, I.I., The Paleolithic of the Eastern Mediterranean, in *Paleolit Blizhnego i Srednego Vostoka. Paleolit Mira* (The Paleolithic of the Near and Middle East. The Paleolithic of the World), Leningrad: Nauka, 1978, pp. 9–189.

Laukhin, S.A., Ronen, A., Tsatskin, A., *et al.*, New Data on the Early Paleolithic of the Western Part of South Levant, *Drevnosti*, 1996, no. 19, pp. 65–67.

Laukhin, S.A., Ranov, V.A., Ronen, A., and Volgina, V.A., The Early Paleolithic of Israel, *Priroda*, 1998, no. 4, pp. 52–68.

Mercier, N., Valladas, H., Valladas, G., *et al.*, TL-Dates of Burnt Flints from Jelinek's Excavations at Tabun and Their Implications, *J. Archaeol. Sci.*, 1995, no. 22, pp. 495–509.

Metody i rezul'taty paleomagnitnogo izucheniya osadochnykh formatsii Zapadnoi Sibiri (Methods and Results of Paleomagnetic Studies of Sedimentary Formations in the West Siberia), Novosibirsk: Nauka, 1973.

Petrova, G.N., Nechaeva, T.B., and Pospelova, G.A., *Kharakternye izmeneniya geomagnitnogo polya v proshlom* (Characteristic Changes in the Past Geomagnetic Field), Moscow: Nauka, 1992.

Ranov, V.A., *Kamennyi vek Yuzhnogo Tadzhikistana i Pamira* (The Stone Age of Southern Tajikistan and the Pamirs), Novosibirsk: IIFF, 1988.

Ronen, A., The Lower Paleolithic Site Evron-Quarry in Western Galilee, Israel, *Sonderveroff. Geol. Inst. Univ. Köln*, 1991a, vol. 82, pp. 187–212.

Ronen, A., The Yiron-Gravellithic Assemblage Artefacts Older than 2.4 Ma in Israel, *Archaeol. Korrespond.*, 1991b, no. 22, pp. 159–164.

Ronen, A., Tabun Cave, *Before Modern Humans 400–200 Ka. The Yabrudian and Micoquin in the Levant and Europe. Guidebook of Excursion*, Univ. Haifa, 1996, pp. 3–6.

Ronen, A., Gilead, D., and Meller, B., Notes on the Pleistocene Geology and Prehistory of the Central Dishon Valley, Upper Galilee, Israel, *Quaternary*, 1974, vol. 25, pp. 13–23.

Ronen, A., Inbar, M., Klein, M., and Brunnaker, K., Artefact-Bearing Gravels beneath the Yiron Basalt, *Israel J. Earth Sci.*, 1980, vol. 29, pp. 221–226.

Ronen, A., Burdukiewicz, J.M., Laukhin, S.A., *et al.*, The Lower Paleolithic Site Bizat Ruhama in the Northern Negev, Israel, *Archaeol. Korrespond.*, 1998, no. 28, pp. 163–173.

Ronen, A., Tsatskin, A., and Laukhin, S.A., The Genesis and Age of Mousterian Paleosoils in the Carmel Coastal Plain, Israel, in *Dorothy Garrod and the Progress of the Paleolithic*, Oxford: Oxbow Books, 1999, pp. 135–151.

Tsatskin, A. and Ronen, A., Micromorphology of a Mousterian Paleosoil in Aeolianites at the Site Habonim, Israel, *Catena*, vol. 34, pp. 365–384.

Vlasov, V.K. and Kulikov, O.A., *Radiotermolyuminestsentnyi metod datirovaniya rykhlykh otlozhenii* (Radiotermoluminescence Dating of Soft Deposits), Moscow: Mosk. Gos. Univ., 1988.

Vlasov, V.K. and Kulikov, A., Radiotermoluminescence Dating to Pleistocene Sediments, *Phis. Chem. Minerals*, 1989, no. 16, pp. 551–558.

Western-Evron, M., Lang, B., Ilani, S., Steinitz, G., and Kaufman, D.K., K/Ar Dating as a Mean of Sourcing Levantine Epipaleolithic Basalt Implements, *Archaeometry*, 1995, vol. 1, no. 37, pp. 37–40.

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 511–525. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 96–110.
Original Russian Text Copyright © 2000 by Belousov.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Angular Unconformities in the Turkestan–Alai Region and Correlated Geological Events of the Carboniferous Time

V. I. Belousov

Kyrgyz Geophysical Expedition, Kyrgyzstan Geological Survey, Shopokovo-1, 722110 Kyrgyzstan

Received July 13, 1999

Abstract—The Middle–Late Carboniferous events in sedimentation, tectonics, magmatism, and ore formation are correlated using paleotectonic reconstructions for the convergence zone between the Alai and Kyrgyz continents. The pre-Bashkirian folding and angular unconformities originated here during the early collision between lithospheric plates that also gave rise to the continental subduction progressing till the end of the Permian. Interaction of the Alai and Kyrgyz continents with the Karachatyr microcontinent, which was distinguished between them, actuated two subduction–collision zones that functioned until the terminal late Moscovian time being responsible for the collision magmatism and mineral deposition. That interaction also resulted in the two-member (cyclic) structure of the flysch–olistostrome formation. According to the reconstructions, the continental subduction of the Late Paleozoic time was dipping northward.

Key words: *subduction, collision, angular unconformities, magmatism, flysch, tectonic sheets, olistostrome, allochthonous ore deposits*

In this work, I consider angular unconformities at the boundary between the Lower and Middle Carboniferous—two most dramatic (in terms of Zonenshain, 1979) epochs in the geological history of the Urals–Mongolia foldbelt. In available summaries on geology of the Turkestan–Alay region (Rezvoi, 1959; Kukhtikov, 1968; Porshnyakov, 1973; Biske, 1996), these manifestations of the early diastrophism are inadequately elucidated, and they remained enigmatic to me for a long period, when I surveyed bauxite deposits of the region. Recent achievements of plate tectonics offer, however, a possibility to solve not only this, but also many other problems of the regional geology, including such a complex and important issue as the correlation of geological events in the Turkestan–Alay region. Known correlations of this kind (Rezvoi, 1959; Kukhtikov, 1968; Porshnyakov, 1973; Burtman, 1990; Biske, 1996; Belousov, 1998) are contradictory not only owing to differences in the individual geological ideas, but also and mainly due to the incompleteness of local geological records in this region very "adverse" for the "normal" stratigraphy, as even basic stratigraphic concepts of "formation" and "stratotype" are frequently very conditional here (Belousov, 1997a).

ANGULAR UNCONFORMITIES

In the Turkestan–Alay region, angular unconformities of the early Bashkirian age can be frequently observed at the base of the Bashkirian–lower Moscovian bauxite-bearing deposits well exposed in carbonate shelf sections, but they are rare in coeval siliceous–carbonate–terrigenous deposits of the continental slope and rise. In the present structure of the region, bauxites and angular unconformities are typical only of the thrust sheets composing the flysch–olistostrome formation (Belousov and Baer, 1989) being unknown in the underlying carbonate sequence (Fig. 1). First data of Konnov (1972) and Porshnyakov (1973), who reported on unconformity between the Lower and Middle Carboniferous limestones (Fig. 2), were soon supported by Banogin (1978), who recognized angular unconformities at the base of bauxite-bearing limestone sequences in the Aktur, Katranbashi, Akshagyl, and Andygen mountains. Below, I consider other examples of these geological relationships and present paleontological characteristics of relevant rocks based on data obtained by V.P. Skvortsov.

In the Katranbashi Mountains, at the left side of the Charatash Creek, the Upper Devonian–Tournaisian limestone beds are discordantly overlain by the bauxite-bearing sequence of grainstones and clastic limestones. The latter yielded the Namurian–Middle Carboniferous assemblage of foraminifers *Pseudoglomospira vulgaris* (Lip.), *Eolasiodiscus ?* sp., *Neoarchaediscus parvus* (Raus.), *Monotaxinoides priscus* Brazhn. et Jarz., *Howchinia subplans* (Brazhn. et Jarz.), and *Asteroarchaediscus pustulus* (Grozd. et Leb.). When became acquainted with microfauna from the sequence, B.V. Poyarkov concluded that the host rocks are of the early Bashkirian age. At the aforementioned site, the lower part of the bauxite-bearing sequence consists of limestone breccia intercalated with allite lentils (Fig. 3, *3*). The unconformity is clearly seen in exposures at the

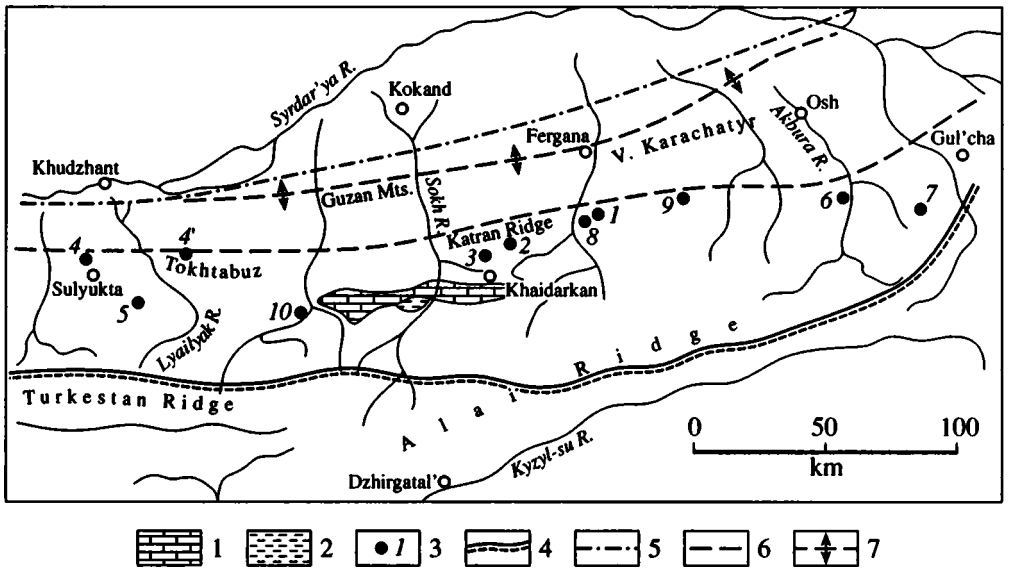


Fig. 1. Geological scheme of the northern Turkestan–Alai piedmonts and localities of studied angular unconformities in the allochthonous carbonate complexes: (1) autochthonous Alai-type sections; (2) underlying terrigenous formation; (3) thrust sheets, olistostromes, molasses, and Mesozoic–Cenozoic deposits overlying the Upper Paleozoic flysch of the Alai zone. Studied localities of angular unconformities: (*1*) Karangly; (*2*) Kantrantau; (*3*) Katranbashi (Charatash, altitude mark of 2792.7 m, Zarkhar); (*4*) Almoly; (*4'*) Kuroson–Khodzhabakyrgan interfluve; (*5*) Kokchetau; (*6*) Altyn–Kazyk–Gupukan; (*7*) Aktur; (*8*) Karabii; (*9*) Chimkaitau; (*10*) Vorukh; (4) boundary between the Alai and Zeravshan–Turkestan zones; (5, 6) ophiolite sutures of Turkestan (5) and Karachatyr marginal sea (6); (7) axis of the South Fergana gravity maximum corrected for influence of unconsolidated deposits.

right-hand side of the Charatash Creek, where limestones, the host rocks of bauxite deposits, yielded *Neoarchaediscus gregoryi* (Dain.), *Asteroarchaediscus* sp. indet., and *Eolasiodiscus* sp. (Namurian–basal Bashkirian stages). Species found downstream from the last site are *Diplosphaerina maljawkini* (Mikh.), *Pseudoglomospira elegans* (Lip.), and *Lasiodiscus* sp. (terminal Namurian–Upper Carboniferous).

To the southeast of the Charatash Creek head (Fig. 3, *3a*), the Middle Devonian limestones and dolomites are separated by an angular and azimuthal unconformity from the overlying member of limestones and clastic rocks. The member yielded the Middle Carboniferous *Glomospiroides* sp., *Glomospiroides fursenkoi* Reitl., and *Neoarchaediscus* sp. in association with *Tuberitina magna* Pojark., *Globivalvulina minima* Reitl., *G. moderata* Reitl., and *Asteroarchaediscus* ex gr. *baschkiricus* (Krest. et Theod.) characteristic of the upper Lower and lower Middle Carboniferous. The member is crowned with a breccia horizon composed of limestone, chert, and shale fragments. The discordant upper boundary of the bauxite-bearing deposits was also traced westward of the Charatash Creek (Fig. 3, *3b*), where the Namurian–Middle Carboniferous *Tuberitina magna* Pojark., *Eotuberitina reitlingerae* M.-Maclay, and Lasiodiscidae gen. et sp. indet were collected, in association with Namurian Archaediscidae gen. et sp. indet., *Eolasiodiscus* sp., and *Howchinia subconica* Brazhn. et Jarz., from limestones exposed along the distance of several kilometers. In this area, like in all others, the bauxite-bearing sequence is overlain conformably or above the erosion surface by the lower–middle Moscovian deposits divisible into chert–limestone–shale, sandstone–clay, and clastic members.

An unconformity characterizing the Tokhtabuz carbonate-type section of the Tokhtabuz–Sulyukta structure in the Almoly Mountains is shown in Fig. 3, *4*. Predominant here among limestones are clastic varieties bearing *Eostaffella* sp., *Tetrataxis* sp., *Propermodiscus* sp., and Textulariidae gen. et sp. indet. In opinion of Skvortsov, age of these remains spans the Visean–Bashkirian interval. In the vicinity of the Murgun Creek head located eastward, the same rocks yielded *Eostaffella* sp., *Eostaffella* cf. *postmosquensis* Kir., *Tuberitina magna* Pojark., and *Bradyina cribrostomata* Rauser et Reitl. of the Namurian–Middle Carboniferous age.

In the Khodzhabakyrgan–Kuroson interfluve area (Fig. 3, *4a*), the bauxite-bearing deposits are characterized by appearance of breccia and cherty limestone in the sequence. Microfauna from limestone beds discordantly occurring here corresponds in age to the Early–Middle Carboniferous.

In the Kokchetau Mountains located southward, the Bashkirian limestones with bauxite intercalations (Peive, 1937) locally overlie the Visean deposits with a sharp unconformity (Fig. 3, *5*). Here, the basal conglomerate and breccia lentils consisting of blocks and fragments of the Visean and Bashkirian limestones mark the lower boundary of the bauxite-bearing sequence. The Middle–Upper Carboniferous unconfor-

mity is also detected in the Altyn-Kazyk–Gupukan Mountains, where it is traceable along the distance of twenty kilometers in the Akbura–Kyrk-Kichik interfluve area. Limestone beds above the unconformity were dated back to the late Serpukhovian–Bashkirian (Porshnyakov, 1973; Biske, 1996), but the pisolitic bauxite bodies present between the beds (Fig. 3, *6*) are most characteristic of the Bashkirian Stage. In the last region, the maximum angular and azimuthal unconformities are as great as 55° and 70°, respectively. Unconformities of similar amplitudes are detected as well in several sites of the Aktur Mountains: at the right-hand side of the Agatan Creek (Fig. 3, *7*); near the Kyrk-Kichik Pass; and along both sides of the Gurmondan River, where limestone beds occurring below the unconformity yield the early Bashkirian foraminifers.

In the lower thrust sheets of carbonate rocks (sections of the Alai type), angular unconformities are less widespread and lower in amplitude than in the upper structural units (Fig. 4). These unconformities are detected in allochthonous limestone units exposed at the Chachme Creek crossing the Arpalyk, Karabii (Fig. 4, *8*), Chimkaitau (Fig. 4, *9*), and Aktash mountains, and also in the Vorukh allite deposit at the left side of the Karavshin Creek (Fig. 4, *10*). At the last site, pelitomorphic and granular limestones of the Serpukhovian Stage are discordantly overlain by dark gray granular limestones of the clastic or organogenic-clastic types. The sequence of the latter encloses cherty interbeds at many levels and interbeds of variegated clayey siltstone and marl in the basal portion. The limestone beds bear *Pseudostaffella* ex gr. *antiqua* Dutk., *Ps. praegorskyi* Raus., *Neoarchaediscus gregoryi* (Dain.), and *Propermodiscus titanicus* (Reitl.), which enable their correlation with the upper part of the Bedak Horizon distinguished by Solov'eva (1963) as the lower substage of the Bashkirian Stage in the stratotype located not far away from the site under consideration. Limestones overlying these beds yield *Ozawainella* sp., *Pseudostaffella* ex gr. *antiqua* Dutk., and Fusulinidae gen. et sp. indet. typical, according to A.V. Dzhenchuraeva, of the upper Bashkirian Substage. Between these limestones and overlying lower Moscovian deposits, there is an erosional surface.

Summarizing data on angular unconformities, I should mention that, being widespread in the Turkestan–Alay region, they are nevertheless isolated and cannot be detected in particular structures. In all type sections, successions of Bashkirian limestone beds are usually intercalated with conglomerate and breccia interbeds; in addition, they bear the redeposited Devonian–Lower Carboniferous fossils.

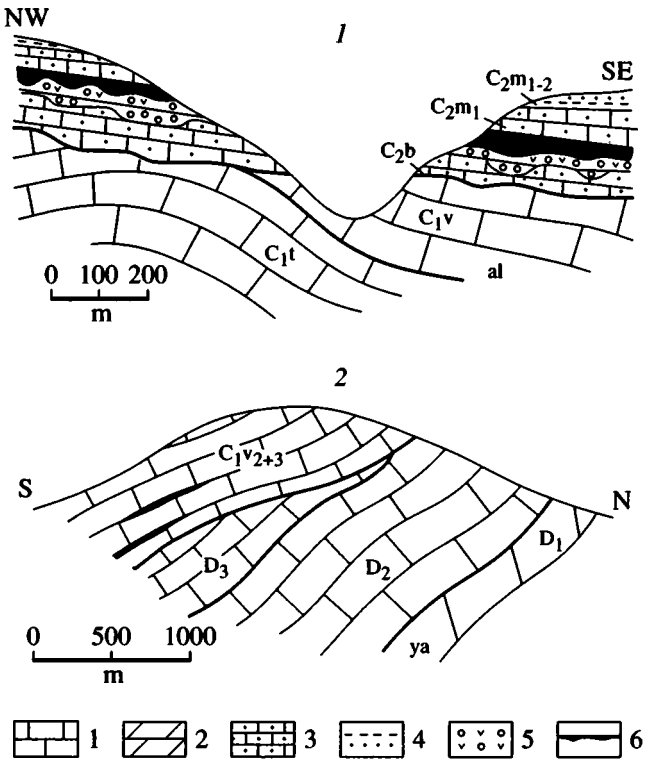


Fig. 2. Angular unconformities in the Alai (AL) and Yauruntuz (YA) type sections, the Karangly (*1*) and Katrantau (*2*) localities according to data of V.B. Goryanov and G.S. Porshnyakov with modifications.

Pre-folding deposits: (1) limestones and (2) dolomites; post-folding deposits: (3) clastic conglomerate-like grainstones; (4) clayey slates and sandstones predating flysch; (5) limestone conglomerates with bauxite–clay matrix; (6) interbeds and lentils of allite and bauxite.

GEOLOGICAL EVENTS

Tectonics and Sedimentation

The considered unconformities postdated an important event—the opening of the Turkestan paleoocean and Karachatyr marginal sea in the Vendian–Early Paleozoic, when the Aktur–Katranbashi block, or the Karachatyr microcontinent, was split off the Alai continent (Belousov, 1998). In the terminal Carboniferous, when the oceanic crust of indicated basins was consumed in subduction zones, all three continental plates (Alai, Karachatyr, and Kyrgyz; see Fig. 6) simultaneously collided that caused folding in their margins. Diastrophism was most intense within the Karachatyr block of a thinned continental crust that was squeezed between the Alai and Kyrgyz plates. Precisely this situation appears to be responsible for a higher amplitude of pre-Bashkirian deformations and angular unconformities in the block as compared to those in adjacent convergent plates. Another feature characterizing these unconformities, namely, their localization in particular areas, seems to reflect the local activation of fracture zones. And finally, the frequent azimuthal unconformities suggest that the convergent boundaries have been oriented not at the right angles relative to the plate movement vectors. Consequently, they mark episodes of oblique subduction responsible for appearance of diagonal tectonic patterns. Thus, the former latitudinal

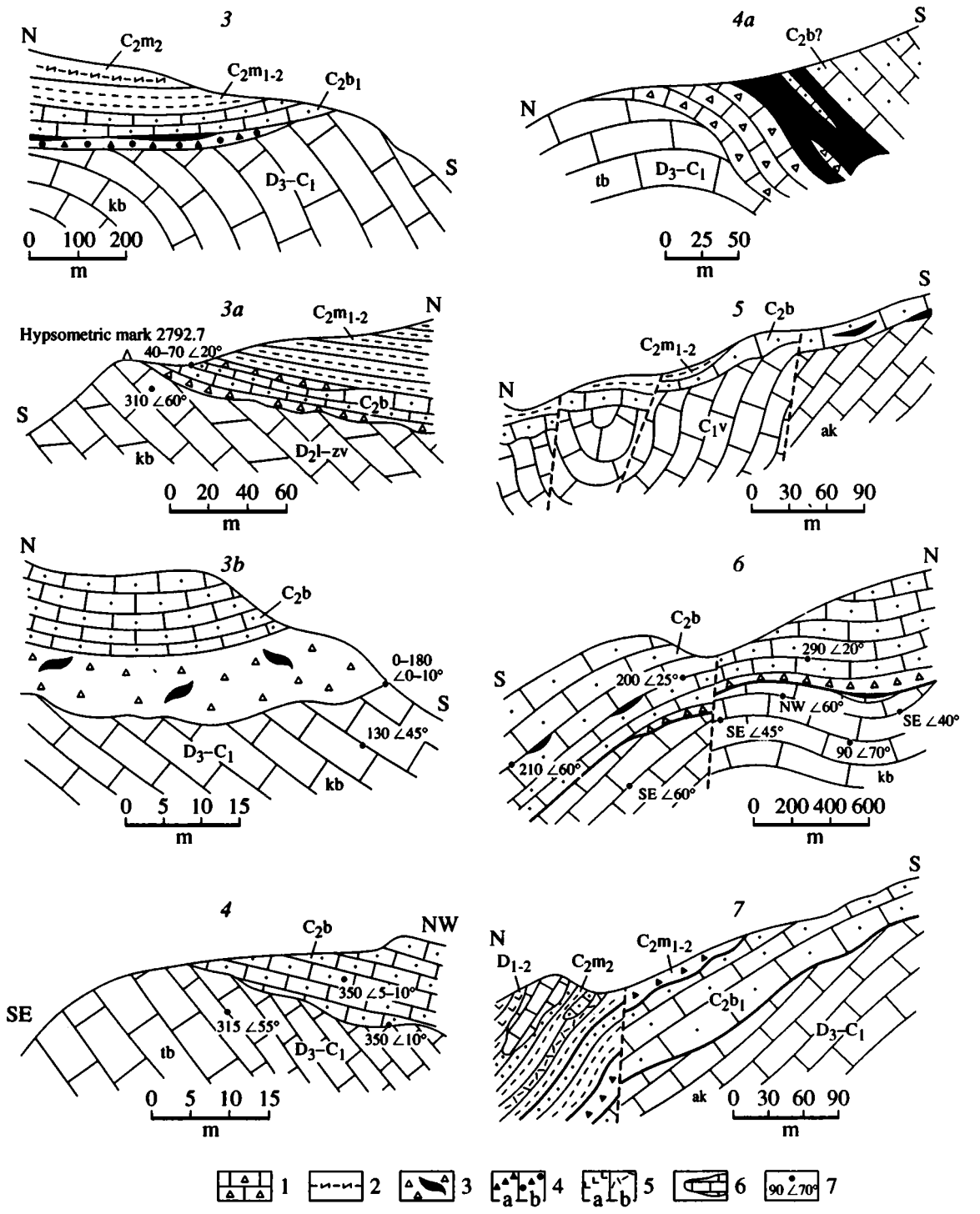


Fig. 3. Exposures of the Aktur (AK), Tokhtabuz (TB), and Katranbashi (KB) type sections illustrating angular unconformities in the allochthonous thrust sheets and olistoliths: (1) brecciated limestone; (2) siliceous and clayey slates (flysch); (3) carbonate breccia with bauxite nests; (4) bauxite–limestone breccia (a) and conglobreccia with bauxite nests and lentils (b); (5) basaltic porphyrite (a) and tuff of basic composition (b); (6) carbonate olistoliths; (7) strike and dip of bedding (other symbols as in Fig. 2).

structural zoning was complicated in the initial Middle Carboniferous by diagonal tectonic elements that determined a new structural arrangement of the Late Paleozoic metallogenic zones (Popov *et al.*, 1979).

According to Khain and Lomize (1995), an analogous development of folding in mobile belts is related to episodes of partial collision that predates the general, final orogenic phase in the belts. In opinion of Popov

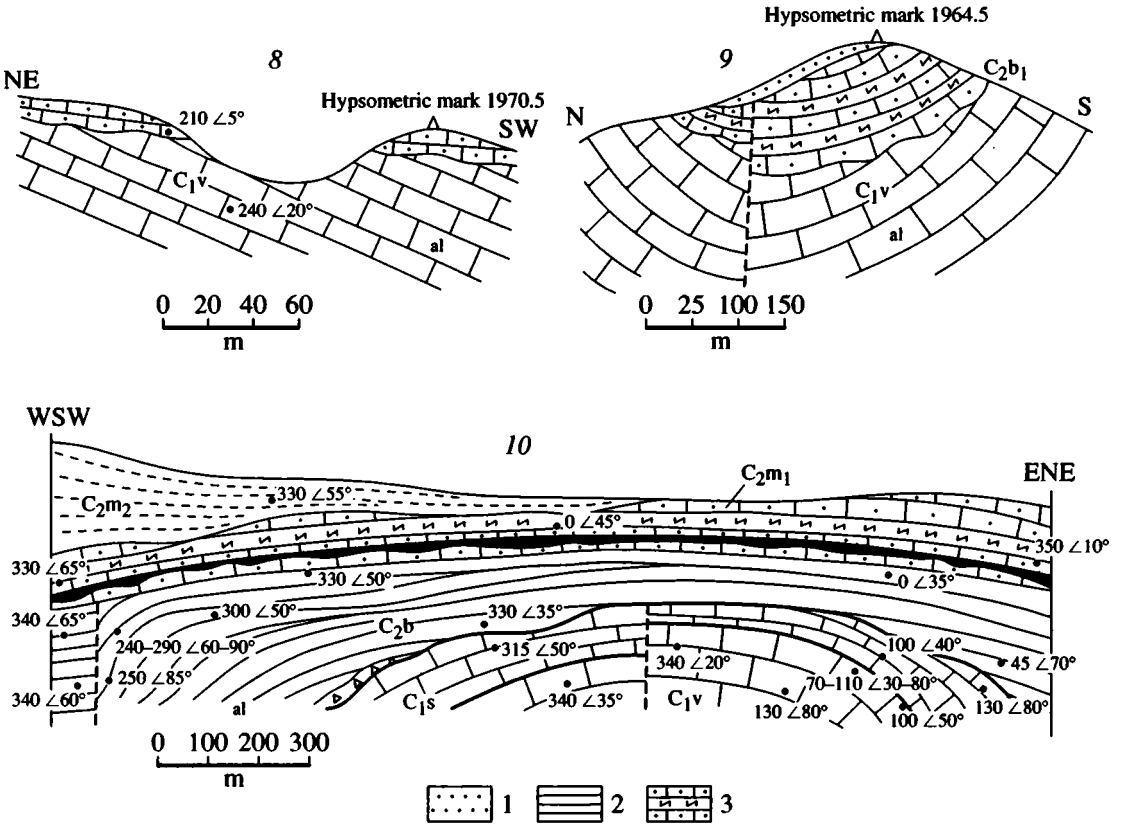


Fig. 4. Sections of the Alai type (AL) displaying angular unconformities in carbonate allochthons: (1) loose deposits; (2, 3) limestone beds with cherty interlayers of the Bashkirian Stage (2) and late Moscovian Substage (3); other symbols as in Figs. 2 and 3.

(1972), the pre-Bashkirian folding in the southern Tien Shan represents not the main, but a preliminary orogenic phase that was insufficiently intense and created not very contrast, wavy relief. Minor uplifts with weathering crusts after basic volcanics rose above carbonate rocks eroded to the peneplain. These uplifts served as provenances of bauxite material deposited at the limestone surface in marginal areas of carbonate platforms, which had the Alai type section in the south and the Aktur, Yauruntuz, Tokhtabuz, and Katranbashi type sections in the northern Karachatyr region (Fig. 6, *1*).

In the terminal Early Carboniferous, first thrust faults and sheets developed in the Alai and Karachatyr forelands.[1] The thrust sheets consisted of several allochthonous units, distinguished among which are terrigenous or carbonate–cherty–terrigenous deposits of continental slope and rise, oceanic crust fragments, Middle Paleozoic oceanic and island-arc volcanics, and shelf deposits of intraoceanic island arcs (Kurenkov *et al.*, 1988; Biske, 1996). At that time, there were also formed the early olistostrome bodies and polymictic melanges enclosing a wide spectrum of rocks exposed at the present erosion level and ranging in lithology from Precambrian metamorphic schists of the crystalline basement to glaucophane schists originated in subduction zones and to shelf limestones. The Tul' polymictic melange of the Alai foreland became a constituent of the Dzhidale flysch–olistostrome complex in response to the thrust-faulting at the late Moscovian time, whereas the Maidan melange that originated in the thrust-fault belt of the Karachatyr foreland (Biske, 1996) was incorporated into the complex of the same name. By the initial Middle Carboniferous, subduction along the active plate margins resulted in formation of accretionary prisms (Fig. 6). In the prism of the Karachatyr active margin, the upper thrust sheets in the north were composed of the platform carbonate–volcanogenic–siliceous and rifting-related formations of the Early Paleozoic age (Vanina, 1987, 1990). Together with underlying thrust sheets of ophiolite rocks and bimodal volcanics of island-arc genesis, they formed the upper allochthon of the Dzhidale flysch–olistostrome complex. Northern trust sheets accreted to the Kyrgyz continent presumably consisted of carbonate, evaporite, and terrigenous deposits of the platform cover that accumulated in the Bosbutau–Kassansai and Kurama zones of the active margin. In the present structure of the Alai Ridge, these rocks occur as concordant thrust sheets within the lower molasse of the foredeep, being exposed as large rock massifs in the northern and

[1] In this work, the term convenient owing to its briefness indicates a part of continental margin adjacent to the subduction zone.

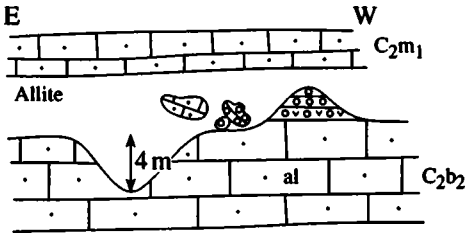


Fig. 5. Fluvial incision at the base of the lower Moscovian limestones as it is seen in exposures at the right side of the Karangly Creek (symbols as in Figs. 2 and 3).

southern slopes of the ridge. Origin of these allochthonous massifs representing the Alai or South Alai type sections of carbonate deposits is disputable (Porshnyakov, 1973; Biske, 1996). The middle part of the prism under consideration presumably enclosed a fragment of the pre-Paleozoic basement of the Karachatyr microcontinent. The Pb–Pb isotopic age of metamorphic schists corresponding to this fragment is 935 ± 60 Ma. Below the fragment and further to the south in the prism, there were thrust sheets of ophiolitic and island-arc volcanic rocks of the Turkestan paleoocean, which later formed the upper ophiolite allochthon of the Alai Ridge (Belousov, 1998). In response to collision of continental masses, the mantle rocks have been thrust over the Karachatyr margin to form the Kan serpentinite melange that encloses blocks of granitoids originated during the previous subduction stage.

In the Bashkirian–early Moscovian period, the foreland seas representing remnants of former basins were still the sites of sedimentation. They accumulated carbonate–cherty–terrigenous rocks composing the upper horizons of the Shalan Group (Shalan and Turtkala formations) in the Alai margin and carbonate molasse in the Karachatyr passive margin (Biske, 1996).

At the beginning of the period, local uplifts appeared near the carbonate platform margins and triggered erosion of bauxite deposits and formation of shallow incision structures (Fig. 5). By the initial late Moscovian time, the upward tectonic movements spread over the remnant troughs and margins of the carbonate platforms, where deposits suffered erosion and karst formation. In the Alai platform, the base of erosion deepened down to the Visean level. At the same time, boulder breccias accumulated near the southern coastal escarpments of the Karachatyr platform, where the karst breccias are over a hundred meters thick (Banogin, 1978), and karst depressions subsided down to the Lower–Middle Devonian limestones. A shallow sea remained only in the central part of the Karachatyr platform, whereas a foredeep that accumulated later the flysch–molasse deposits originated in the inner part of the Alai continental margin in response to subsidence.

The late Moscovian Substage marks the following series of events: accumulation of flysch–olistostrome formation, new phase of folding and thrusting, amalgamation of the Karachatyr microcontinent with the Alai plate, intrusion of minor granodiorite bodies, and sea transgression from the foredeep, which extended northward to meet the advancing thrust sheets. Fig. 6, *2* shows presumable position of root zones for the future tectonic nappes, i.e., the presumable decollements in the sedimentary cover, which determined the tectonic denudation depth in the junction zone of lithospheric plates. These detachment structures show the volume of eroded and tectonically displaced material that accumulated afterward in the flysch–olistostrome complexes (Belousov and Baer, 1989; Belousov, 1997, 1998). In this sense, they determine stratigraphic boundaries of the latter.

The concordant nappes of the Alai Ridge are characterized by a dismembered occurrence of the Upper Paleozoic flysch–olistostrome formation lacking basal tectonites and also by olistostrome aureoles surrounding allochthons. These features suggest the tectonogravitational, synsedimentary origin of the nappes (Belousov, 1997b), in other words, the consecutive detachment of tectonic slices and gravity sliding of the latter into the Alai flysch trough (Fig. 6, *2*). The gravity sliding was likely favored by positive relief forms (Mitchell and Garson, 1984; Khain and Lomize, 1995) arisen within the collision zone in response to the tectonic imbrication and, partially, to the anticlinal arching of subducting plates. The last factor could create a negligible inclination of the detachment surface toward the advancing flysch trough (Fig. 6, *2*) that was important for the gravity sliding. In the course of further underthrusting of plate areas that approached the suture zone, the arching produced a kind of "wave effect" and consequent destruction of platform cover, the tectonic slices of which slid into basin clearing the new space for sea transgression.

The foreland sea came up to the southern active margin of the Karachatyr microcontinent in the middle of the late Moscovian time, when the Alai foreland thrust under the Karachatyr plate with the relevant obduction of limestone and other thrust sheets onto the plate margin. The final collision stage and amalgamation of the microcontinent with the Alai plate were associated with intrusive magmatism that consolidated the suture zone. The subsequent thrusting of imbricated continental crust under the Kyrgyz continent caused the cut-off of the Aktur–Katranbashi carbonate platform and of the Early Carboniferous thrust sheets of the Karachatyr foreland, whose rocks were displaced into the flysch trough. As a result, the Maidan and Sokh-Kyrgyzata complexes joined the Tolubai and Dzhidale complexes that had been accumulated earlier in the trough, and this event was terminal in the history of flysch–olistostrome formation. The sea transgression extended up to the Karachatyr foreland in the middle of the Late Carboniferous time, when the molasse accumulation replaced the flysch sedimentation in the foredeep. The final collision of continental plates, emplacement of large granite intrusions, and amalgamation of

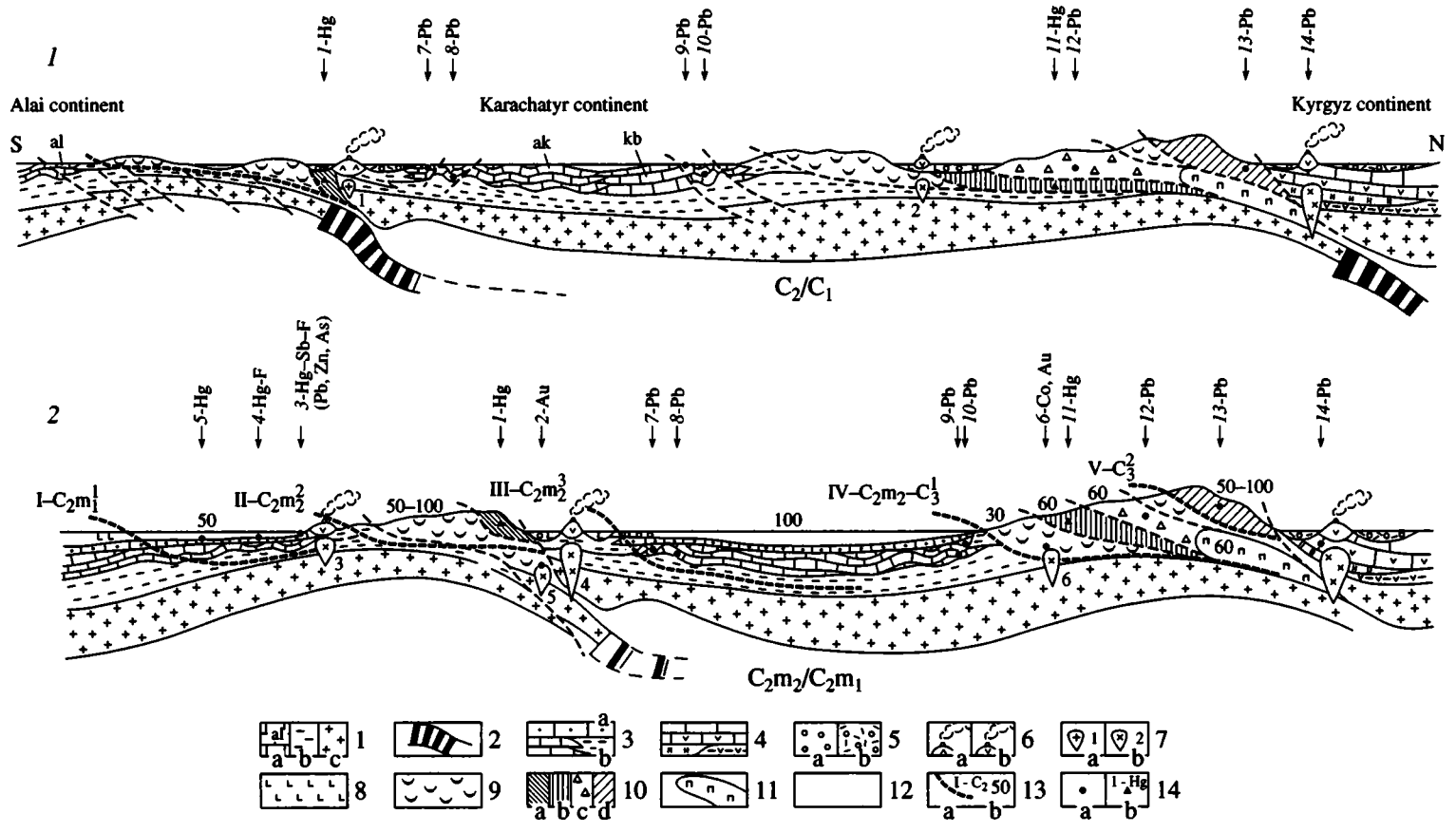


Fig. 6. Paleotectonic reconstruction illustrating geodynamic formation environments of the pre-Bashkirian angular unconformities in the Late Paleozoic thrust sheets of the study region: (1) the Alai (AL, D_2–C_2), Aktur–Yauruntuz–Tokhtabuz (AK, S_2–C_2) and Katranbashi (KB, D_3–C_2) type sections of carbonate rocks (a), sequence (C–S) of terrigenous–volcanogenic–carbonate deposits (b), and consolidated crust (c) of the Altai and Karachatyr continental plates; (2) oceanic crust; (3) limestones (C_2b–C_2m_1) incorporating bauxite deposits (a) and transitional rock facies (b) of shelf and continental slope; (4) carbonate rocks, volcanics, evaporites, and terrigenous deposits of sedimentary cover of the Kyrgyz continent; (5) clastic (a) and volcaniclastic (b) rocks; (6) island-arc calc-alkaline volcanics of subduction (a) and collision (b) stages; (7) intrusive bodies of gabbro, diorite, monzonite, granodiorite, and quartz diorite that originated at the subduction (a) and collision (b) stages; (8) submarine basaltic volcanism; (9) thrust sheets, melange, and early olistostrome of foreland zones; (10) accretionary terrane (platform deposits, island-arc rocks, and lower ophiolite allochthon) of the Karachatyr active margin (a), upper ophiolite allochthon (b), Kan serpentinite melange (c), and carbonate rocks of the Kyrgyz continental margin (d), which bear Pb–Zn mineralization and are intercalated with alkaline volcanics, terrigenous deposits and evaporites; (11) obducted slab of ultramafic rocks; (12) mantle; (13) age of detachment faults (a) and distance (km) separating them (b); (14) Sb–Hg, Pb–Zn, and other mineralization predating the nape formation (a) and listwaenite-type Hg mineralization in serpentinites and basic volcanics (b). Ore deposits by names: (*1*) Chonkoi; (*2*) Turuk; (*3*) Severnoe, (*4*) Plavikovaya Gora and (*5*) Yuzhnoe of the Khaidarkan district; (*6*) Akdzhilga; (*7*) Shorbulak; (*8*) Pum; (*9*) Turabulak; (*10*) Kan-i-Gut; (*11*) Beshbulak; (*12*) Kan; (*13*) Guzan, Kyrkel' and Tekesaldy; (*14*) Sumsar–Bosbutau ore field.

the Alai and Kyrgyz continents took place after obduction of the upper carbonate tectonic slice onto the accretionary prism. At this stage, the remnant foredeep basins accumulated coarse molasses, those of the continental type included. These deposits are indicators of the terminal, late orogenic stage (in terms of Khain and Lomize, 1995) in the mobile belt development.

Thus, the angular unconformities in the Lower–Middle Carboniferous deposits of the Turkestan–Alai region appear to be related to the initial collision stage and are confined to folding zones near the convergent boundaries between continental plates. The same event was likely responsible for the initial development of detachment faults and subsequent trusting of tectonic sheets, which influenced afterward the accumulation of flysch, molasses, and olistostromes. The established pairs of paleotectonic events (two subduction and two collision stages) caused by the Karachatyr block emergence are correlative with the development trend of magmatism and ore genesis, as it is shown below.

Magmatism and Ore Formation

Magmatism characterizing stages of rifting, basin opening, and oceanic crust subduction has been already considered in a series of previous publications (Rezvoi, 1959; Porshnyakov, 1973; *Stratifitsirovannye...*, 1982; Lesnov *et al.*, 1982; Dodonova *et al.*, 1984; Kurenkov, 1983; Kurenkov *et al.*, 1988; Vanina, 1987, 1990; Biske, 1996) thus being outside the scope of this paper. The principal attention is paid here to the problematic collision magmatism of the Turkestan–Alai region, peculiarities of which are inadequately described. However, one aspect of the preceding subduction magmatism deserves a special consideration.

Westward of the Tul' Settlement, at the left side of the Sokh River, the Dzhidale flysch–olistostrome complex encloses tectonic slices of volcanogenic–terrigenous rocks of the Karatash Group. Clayey shales, sandstones, and conglomerates of the group are intercalated with andesitic dacites, trachyandesites, albitophyres, diabase porphyrites, and their tuffs. These volcanic rocks of an island-arc affinity are dated back to the Early–Middle Carboniferous on the basis of paleontological data (Nenakhov *et al.*, 1992). The original position of relevant island arc that arose in the active margin of the Karachatyr microcontinent at the terminal stage of the oceanic crust subduction is shown in Fig. 6, *1*. In the present-day regional structure, the Karatash tectonic sheets overlie the allochthonous bodies of the Tul' polymictic melange enclosing blocks of Visean limestones. The island-arc volcanism in the Karachatyr active margin could still be in progress during the Middle Carboniferous collision stage, because the bauxite deposits in the Aktur and Tokhtabuz type sections of carbonate rocks show sometimes a considerable admixture of volcanic hyaloclastites. Manifestations of volcanic activity apparently were local, characterizing the decreased subduction angle of the Alai plate that is thought to be a factor responsible for the magmatic activity decline at continental margins (Khain and Lomize, 1995).

The early collision magmatism in the Karachatyr foreland is represented by basic lavas and tuffs intercalated with graywackes in the upper allochthonous units of the Maidan flysch–olistostrome complex (Fig. 6, *1–2*). In the Koshmoinak–Dzhiptyksu interfluve area, the Sokh-Kyrgyzata complex rests on basal olistostrome and siliciclastic flysch incorporating rock slices that are composed of rhythmically alternating tuffoconglomerates, breccias, graywackes, and clayey to siliceous shales, among which there are horizons of tuff, porphyrite, and olistostrome (Belousov, 1998). Fossils that have been collected in this area from blocks and interlayers of clastic limestones are redeposited and variable in age. Youngest among them are Namurian foraminifers *Tuberitina magna* Pojark., *Propermodiscus* sp., *Howchinia gibba* (Moell.), and *H. subconica* (Brazhn. et Jarz.). The underlying terrigenous deposits are attributed to the Middle Carboniferous (Kotel'nikov, 1973), but the boundary separating the units under consideration appear to be tectonic. In the Kan-i-Gut area, interlayers of detrital limestones occurring in an allochthonous complex of basalts, tuffs, and siliciclastic rocks yielded foraminifers, characteristic, in opinion of N.A. Redichkin, of the lower Middle Carboniferous, most likely of the Bashkirian Stage (Belousov, 1998). The Early–Middle Carboniferous age was also established for volcanogenic–cherty–terrigenous deposits of the Sartale site (Belousov, 1980), where they are intercalated with tuffs and Ol-porphyrite interlayers. Formerly, these deposits were attributed to the Silurian, or to the matrix of the flysch–olistostrome formation. Rocks of similar composition and structure are characteristic of the Khodzhagair, Chilesai, Chugam, and Turabulak formations, which enclose the Namurian? olistostrome bodies (Makarychev, 1979). These rocks presumably accumulated during the same sedimentation cycle. According to similarities in lithological composition, structure, and fossil assemblages, the volcanogenic–graywacke sequences of all aforementioned areas originated in uniform settings of the remnant paleobasin of the Karachatyr passive margin (Fig. 6, *1–2*), and thus, they may characterize a single cycle of island-arc volcanism of the Bashkirian Stage. If this is correct, the early Middle Carboniferous transition from subduction to collision magmatism was concurrent in the Turkestan–Alai region and southern margin of the Kyrgyz continent, where the volcano-plutonic belt begun to form since that moment (Biske, 1996).

At the terminal early Moscovian time of initiation of the Alai flysch trough, basic tuffs were deposited among the bauxite-bearing limestones of the Alai foreland. Later on, at the commencement of the late Moscovian time, the backward zone of the Alai carbonate platform was affected by submarine eruptions of Ol-basalts, whose thin interbeds are exposed in the Tolubai flysch sequence near the Bedak Settlement (Fig. 6, *2*).

In the frontal part of the Alai platform, the Tolubai flysch accumulation postdated episodes of granitoid magmatism, the uplift and erosion of carbonate rocks, and also the subaerial rhyolite–dacitic volcanism (Fig. 6, *2*; 3); the latter was responsible for genesis of the Khaidarkan, Kadamdzhai, and other Sb–Hg deposits of the jasperoid type (Fig. 6, *2*; *3*-Hg–Sb–F, *4*-Hg-F, and *5*-Hg).

The Tolubai flysch-olistostrome complex includes fragments, blocks, and tectonic slices of intermediate to acidic volcanics, some representing dismembered subvolcanic dikes and lava sheets occurring at the top of limestone slices. These magmatic rocks of olistostrome horizons associate with blocks of jasperoids and ore breccias, being comparable with the latter in the enrichment degree by ore components (Hg, Sb, and F). At the Vostochnaya Vershina site of the Khaidarkan area, one of the olistostrome blocks exhibits the following rock sequence (from the base upward): limestone of few meters thick, jasperoids (1–3 m), silicified rhyolite, rhyodacite, and secondary quartzite (6–8 m). At the Novoe ore deposit, the shale–limestone slice in olistostrome encloses felsic and phyric rhyolite dikes (5–15 m) crosscutting the Lower–Middle Carboniferous limestones, the ore zone, and overlying shales. One of the dikes bears polymetallic ores superimposed on the primary Sb–Hg ore breccia. Between the Slantsevyi Klin and Sur'myanyi Greben' localities of the Kadamdzhai ore field, a slice of Visean limestones in olistostrome has an erosion surface covered with andesitic to acidic lavas and their tuffs (Berger and Natal'in, 1989; Natal'in, 1992) filling sublatitudinal scours at the limestone surface. Within areas of the Abshir, Kadamdzhai, and Khaidarkan ore fields, fragments of ore-bearing rhyolites and andesites were found in olistostrome horizons exposed at the Kapchigai, Sur'myanyi Greben', Karabii, Kara-Archa, and Dange sites.

Comagmatic intrusive rocks were recognized only at the Bulat site of the Abshir ore field, where a rounded granodiorite block and associated boulders of ore breccia are exposed as components of the Tolubai flysch in the mining gallery 22 (Bochkarev, 1952). The exocontact metasomatites are more widespread, being represented by skarn blocks, boulders, and pebbles in the Abshir ore field (Bochkarev, 1952), and also by fragments of sericite–plagioclase–quarts hornfels at the Bulat, Kapchigai, Sur'myanyi Greben', and Novoe localities. One exposure at the Kapchigai site is especially interesting, as it exhibits an ore-breccia block enclosing a skarn boulder (0.5 × 1 m) and, thus, suggests that granitoid intrusions predated the ore formation. In general, the age succession of magmatic rocks, which have been formed in the frontal part of the Alai carbonate platform during the initial late Moscovian time, is as follows: granodiorite–andesite and rhyolite (Sb, Hg)–felsitic dikes (polymetallic ores).

The late Moscovian intrusions of porphyritic plagiogranite and quartz porphyry, as well as concurrent eruptions of rhyolitic, andesitic, and basaltic lavas displaying the hyperclarke concentrations of lead, zinc, manganese, and silver, were characteristic of the Karachatyr active margin (Fig. 6, *2–4*). Blocks and smaller fragments of these rocks occur in olistostrome and melange bodies exposed at the right-hand side of the Zarkhar Creek. The same magmatic cycle presumably was responsible for deposition of silicified tuffs of quartz porphyry. The tuffs form the top cover above limestone beds of an olistolith exposed in the foothills of the Ulugtau Ridge. Blocks of rhyodacite, porphyritic rhyolite, and tuffs with a high Hg and Mn content are known in the Dzhidale olistostrome at the Sharan Creek locality; they may also represent the products of concurrent magmatic activity.

Small plutonic bodies intruded the Karachatyr suture zone (Fig. 6, *2–5*) at the mid-late Moscovian time. Subsequently, olistoliths consisting of proper magmatic rocks and host schists were incorporated into the Dzhidale flysch. At the Khaidarkan locality in the left side of the Zarkhar Creek, a small (few meters across) stock of dolerite and gabbro cutting the schists is enriched in tin (0.2%), lead, and silver. At the right side of the creek, the hornfels zone surrounding the quartz-diorite body (15 m across) bears the gold mineralization. The Turuk intrusion of granodiorite, quartz diorite, and monzonite, which is located with similar structural relations in the Akbura River headstream, produced an insignificant contact metamorphism in the host rocks of the Dzhidale complex. The complex includes boulders and blocks of tactites, tremolite rocks, and rhyolitic porphyry, and this situation supports the opinion of Dodonova and her colleagues (1984) that the Turuk intrusion is of the Middle Carboniferous age. The above rocks show the hyperclarke Sn and Sc concentrations, whereas the tactite aureole is enriched in gold (Fig. 6, *2*, 2-Au).

The terminal stage of deposition of the flysch–olistostrome formation was concurrent to the new phase of continental collision at the Middle–Late Carboniferous boundary time. This event caused an intense intrusive magmatism in the Turkestan suture zone and in the southern margin of the Kyrgyz continent. Within the southern zone located at that time about 150 km away from the Turkestan suture (Fig. 6, *2–6*), the carbonate and flysch–olistostrome formations were pierced by the Chalkuiryuk, Khodzhakelyan, Gaz, Surmetash, and some other small intrusions of the monzodiorite and granosyenites composition (Dodonova *et al.*, 1984). Comagmatic volcanic rocks correspond to the Agatan Tuff in the Aktur Mountains (Belousov, 1998), where this unit is the uppermost one in the Shyut Formation, and also to acidic tuff beds and trachyandesitic lavas of the Karachatyr region (Biske, 1996). In these rocks, concentrations of tin, tungsten, arsenic, scandium, cobalt, and gold are usually above their clarke values. Allochthonous occurrences of the rocks under consideration are unknown, except for diorite blocks in the Sokh–Kyrgyzata melange exposed at the left bank of the Isfairam Creek.

Thus, the available paleontological data suggest the Bashkirian or early–late Moscovian age of the considered volcanic rocks of basic, intermediate, and acidic composition. These data along with the established relationships between the upper Moscovian deposits and dolerite–granodiorite dikes and intrusive bodies point to the Middle Carboniferous age of the magmatic activity in general. The correlation scheme for the Middle Carboniferous magmatic rocks is presented in Fig. 7.

Subsequent lava eruptions are intercalated with molasses deposited in the foredeep and correspond to diabase porphyrites of the Guzan locality (Belousov, 1998), and also to porphyrites and quartz albitophyres of the Isfara, Batken, and Karatau areas (Rezvoi, 1959). The Late Carboniferous–Early Permian andesitic to dacitic lavas of the Khodzhakelyan site may characterize the same cycle of volcanic activity that probably was interrelated with the collision phase in the southern margin of the Alai continent (Biske, 1996). The terminal stage of collision magmatism and subduction of the continental Alai plate is characterized by several occurrences of volcanic rocks, namely, by acidic tuffs intercalated with the marine molasse in the Karachatyr region, by quartz albitophyres and tuffs exposed along the Achiksu River, and by younger rhyodacite lavas buried in the red molasse of the eastern Karachatyr (Rezvoi, 1959; Biske, 1996).

Disputable as yet is the genesis of Permian granitoid intrusions in the southern slope of the Alai Ridge and in the Alai–Turkestan watershed zone. Corresponding rocks are subdivided into the *I*-, *S*-, and *A*-type granites. In opinion of Biske (1996), intrusions of the first or mixed *I–S* type could be formed above the Vashan (Zeravshan) zone of the oceanic crust subduction under the Alai continent. This idea steams from the earlier concept of Pai (1991), who argued for the past existence of the South Alai oceanic basin located southward of the Alai continent. It seems compatible with the following geological facts: first, in the present day structure, there is a thick (8 km) zone of crustal imbrication that dips northward under the Turkestan–Alay region; second, the flysch formation of the Zeravshan–Turkestan zone includes the middle Paleozoic volcanic and intrusive rocks originated in suprasubduction environments (Peive, 1980; Biske, 1996); and third, the collisional liparite intrusion of the Late Permian time are known in the Lyailyak–Sokh interfluve area of the Turkestan Ridge (Dodonova *et al.*, 1984).

Considering the ore formation history in the Alai Mountains, we should mention first that the lead deposits (with zinc and silver) of the subduction stage are clustered in the middle Paleozoic carbonate rocks. These enigmatic deposits (in terms of V.I. Smirnov) had their roots in two different geodynamic provinces, one of which corresponded to marginal zones of the carbonate platform of the Karachatyr microcontinent (Fig. 6). The Devonian stratigraphic level incorporated here the Pum (*8*-Pb) and Turabulak (*9*-Pb) stratiform sheet deposits, whereas the strata-bounded Shorbulak (*7*-Pb) and Kan-i-Gut (*10*-Pb) deposits of the fractured sheet type were located at the higher Early Carboniferous level. Lead and zinc are thought to have been mobilized from clayey deposits in marginal zones of the platform during the respective events of its tectonic activation (Gorzhevskii, 1989). Afterward, the deposits and their host rocks were displaced into the flysch trough as the constituents of the lower and upper tectonic slices of the Maidan complex (Belousov, 1998).

The second province in the active margin of the Kyrgyz continent corresponded to a zone of mineralized magmatic arcs (terminology of Mitchell and Garson, 1981). In the present-day structure, this is the Bosbutau–Sumsar ore district (Fig. 6, *14*-Pb), where the stratiform Pb–Zn mineralization in limestones show signs of genetic connections with the submarine volcanism, silica accumulation, and fumarole fields (Voitovich, 1983; Voitovich and Donets, 1985). At the commencement of the collision, the ore-bearing carbonate rocks were thrust over the continental slope deposits of the outer arc and became incorporated into the Kan serpentinite melange (the synonymous ore deposit, Fig. 6, *12*-Pb) and also into the accretionary terrane (the Guzan and Karatau ore deposits, Fig. 6, *13*-Pb). The allochthonous position of the Guzan massif in the Upper Carboniferous molasse was recognized many years ago (Rezvoi, 1959; Kukhtikov, 1968). Later on, Voitovich (1979) established the imbricated inner structure of the massif and the allochthonous position of the ore deposit proper. The structural position of alaskites in the allochthonous massif of the Karatau Mountains is similar to that of the Bosbutau granites in the central Tien Shan (Rezvoi, 1959). In addition, the Upper Carboniferous conglomerates in this area include granitoid pebbles, and this may be a result of the secondary allochthonous position of parental granite bodies. Carbonate massifs of the so-called South Alai type sections may represent a continuation of the Karatau–Guzan allochthons (Biske, 1996). In contrast to the Alai sections proper, those of the southern Alai have distinct stratigraphic position (Belousov, 1997b) and include evaporite beds and alkaline volcanic rocks (Nenakhov, 1985) similar to certain volcanics of the Bosbutau Mountains, where their Pb–Zn metallogenic specialization is established (Dodonova *et al.*, 1984).

The Sb–Hg mineralization in jasperoids of the southern Fergana shows signs of genetic connections with the subaerial volcanism of the collision stage. In terms of geodynamics, the Chonkoi ores in listwaenites (Fig. 6, *1*, *1*-Hg) originated within the accretionary terrane added to the active margin of the Karachatyr microcontinent, because the Hg mineralization is typical here of both the ultramafic and island-arc volcanic rocks. In the course of tectonic evolution, the Chonkoi ore deposit was incorporated together with the lower thrust sheet of ophiolitic rocks into the Dzhidale flysch–olistostrome complex. Time limits for the deposit

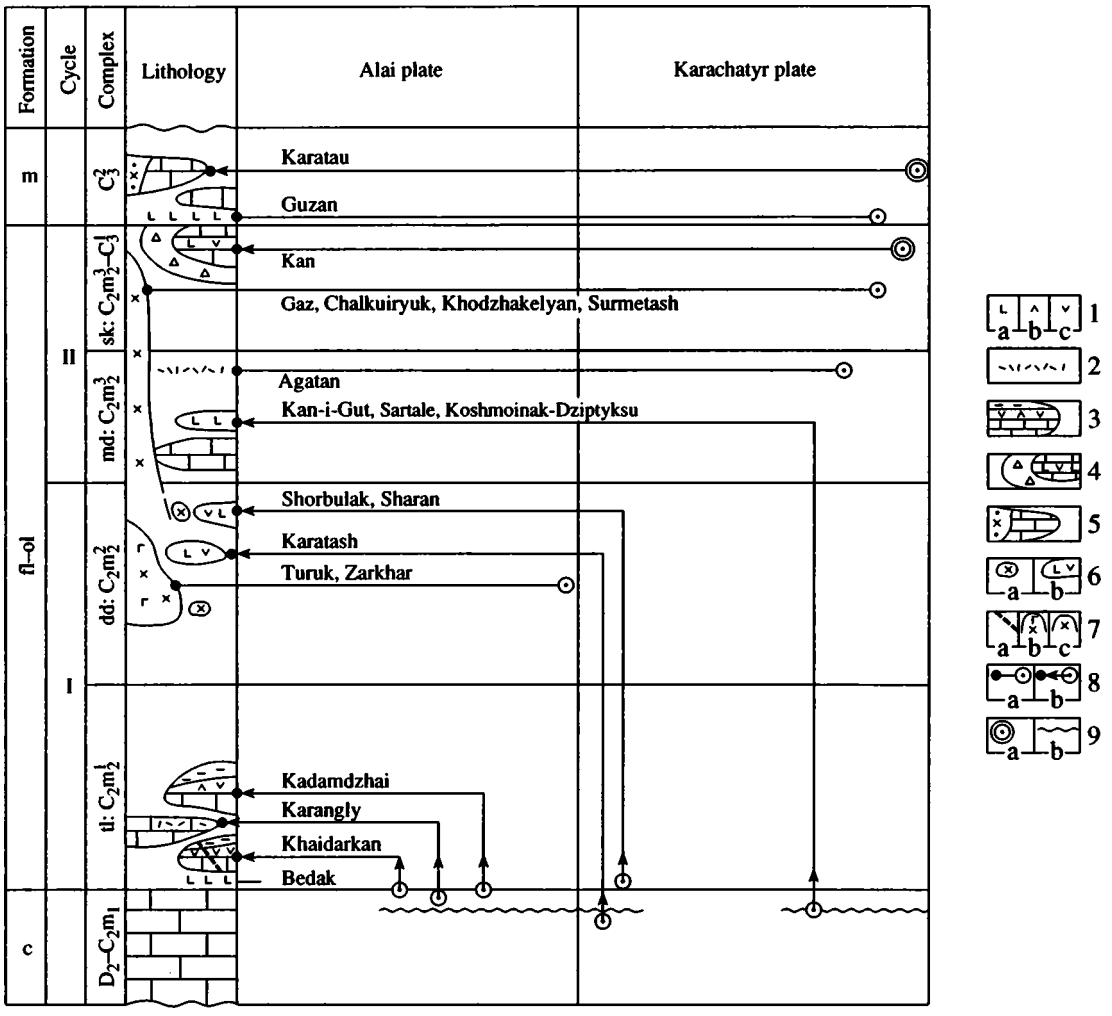


Fig. 7. Correlation scheme of the Middle Carboniferous tectonic and magmatic events: (1) lavas of basic (a), intermediate (b) and acidic (c) composition; (2) tuff of basic composition; (3) tectonic slices of carbonate rocks intercalated with volcanics and slates; (4) Kan serpentinite melange incorporating blocks of Takhmatdanga limestones; (5) huge limestone olistolith hosting the alaskite intrusive body; (6) allochthonous blocks of granitoids (a) and volcanic rocks (b); (7) felsic dikes (a), granodiorite–monzonite–dolerite intrusions (b), and intrusive bodies of monzodiorite–granosyenite composition (c); (8) autochthonous (a) and allochthonous (b) positions of magmatic rocks; (9) thrust sheets accreted to the active margin of the Kyrgyz continent (a) and pre-Bashkirian unconformity (b). Formations: (c) carbonate, (fl–ol) flysch–olistostrome, (m) molasse. Complexes: (tl) Tolubai, (dd) Dzhidale, (md) Maidan, (sk) Sokh–Kyrgyzata.

formation are the terminal Early Carboniferous and the initial late Moscovian. During this period, the quartz–ankerite metasomatism affected the oceanic basalts in the Turkestan suture zone. The mercury mineralization in these basalts is known at the Beshbulak and some other localities (Fig. 6, *1*, *11*-Hg). The mineralized basalts were subsequently thrust over deposits of the Sokh–Kyrgyzata complex as components of the upper ophiolitic allochthons.

Thus, the Late Paleozoic stage of thrusting transformed the considered ore deposits of the Turkestan–Alay region into the allochthonous ore-bearing complexes (Belousov, 1983). As a consequence, the deposits became unfitting the ordinary concept of ore genesis. They require a specific approach to interpretation of their origin, age, and spatial distribution.

To conclude the above consideration, we should mention one more important event in the geological history of the Turkestan–Alay region, namely, the Neogene stage of tectonic thrusting that affected the whole area of the southern Tien Shan (Nechaev *et al.*, 1991). At that stage of crustal section doubling in the study region, both suture zones along with marginal parts of the Mesozoic–Cenozoic depressions and molassic troughs became overridden by allochthonous rock complexes (Fig. 8). In addition, the autochthonous and allochthonous structural units of the carbonate shelf were thrust over the upper tectonic nappes of ophiolitic rocks, and also over the obducted slab of mantle rocks detectable at the deep level in the Karachatyr region (Belousov, 1997b). The Alpine tectonics in the Fergana depression and surrounding structures was responsible

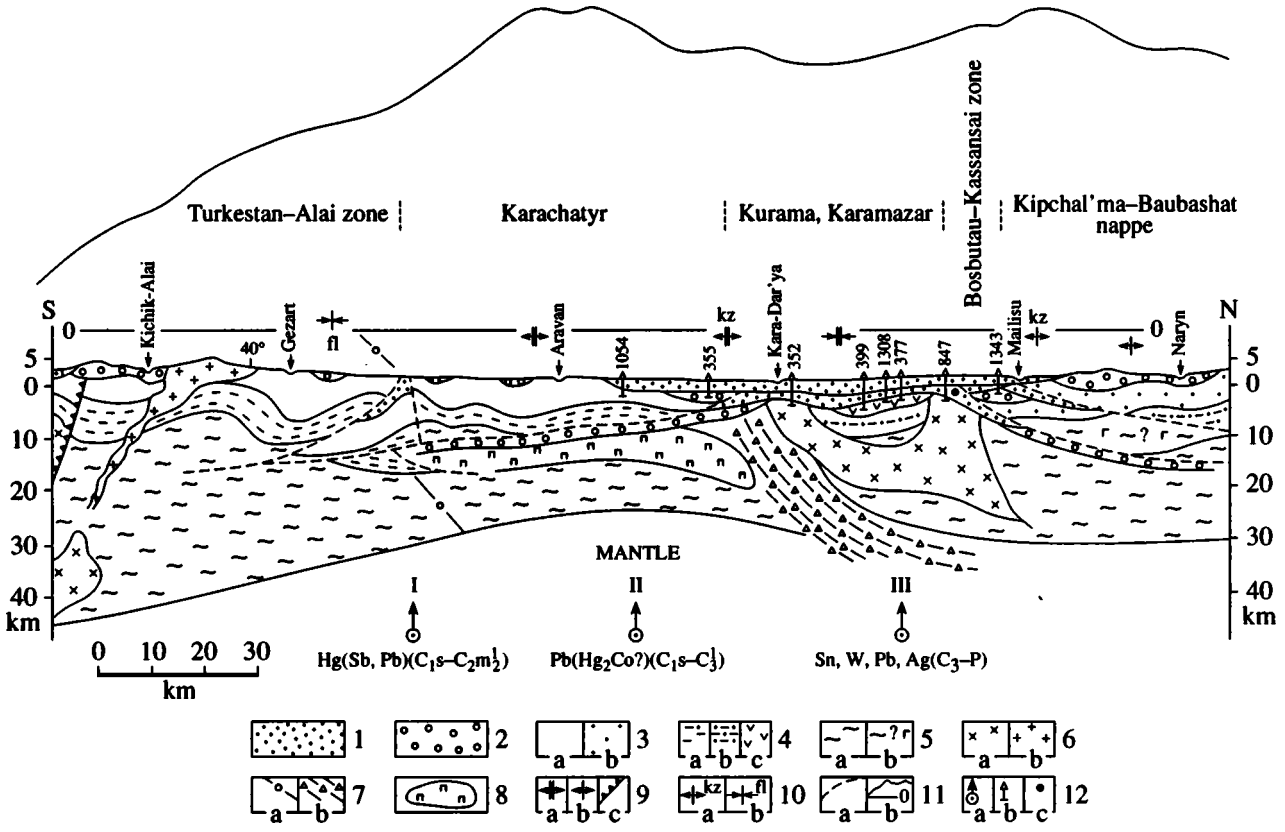


Fig. 8. Physicogeological model of the Fergana depression and surrounding orogenic structures (after Belousov and Lobanchenko, 1990, with modifications): (1) unconsolidated deposits (Mz–Kz); (2) molasse (C_3^2–P); (3) flysch–olistostrome (C_2m_2–C_3^1) and carbonate (D_2–C_2m_1) formations of the Alai plate (a) and carbonate–terrigenous sedimentary cover of the Kyrgyz continent (b); (4) sedimentary cover of the ancient Alai (a) and Kyrgyz (b) platforms, and quartz porphyry (C_2–T_1) of the Kurama zone; (5) consolidated crust (a) and abnormally dense rocks of the Bosbutau–Kassansai zone (b); (6) batholiths (a) and minor intrusions (b) of granitoids; (7) Karachatyr (a) and Turkestan (b) ophiolite sutures; (8) obducted and buried slab of ultramafic rocks; (9) first-fold axis of gravity anomalies corresponding to the South Fergana maximum and minimum (a), second-fold axis of gravity anomalies (b), and zone of maximal horizontal gradient in the gravity field (c); (10) axes of gravity anomalies corrected for influence of unconsolidated deposits (a) and of the Alai flysch trough (b); (11) Alpine thrust faults (a) and profile of Bouguer gravity anomalies (b); (12) inferred sites of mineralizing fluid flows and age of mineralization (a), oil-exploration boreholes (b), and the Minbulak oil reservoir below the thrust plane (c).

for origin of the Minbulak oil reservoir located under the thrust plane and manifesting an abnormally high oil yield. The Karachatyr area adjacent to the Fergana depression in the south (Fig. 8, Aravan) is also intriguing in this respect, because the core sections recovered by drilling show that oil segregations frequently characterize here many rock varieties ranging in age from the Cambrian to Late Carboniferous. According to results of our reconstructions, it seems possible that the oil-producing zone in Mesozoic–Cenozoic depressions of the southern Fergana (the latitude of forty degree) is spatially interrelated with the Turkestan and Karachatyr ophiolitic sutures.

DISCUSSION

Geological events considered above took place at the end of the mature and during the main orogenic stage of the mobile belt evolution (according to terminology of Khain and Lomize, 1995). The pre-Bashkirian angular unconformities originated at the initial phase of the continental collision. Diastrophism related to the subsequent subduction of continental plates at the terminal late Moscovian time and afterward, during the Late Carboniferous and Permian, is inadequately studied, and we can characterize it in a very brief manner.

The incipient collision means a transition from the oceanic to continental subduction that developed under conditions of moderate compression and related formation of thrust sheets. Against these background environments, there were also short periods of crustal extension and magmatic activity. Our correlation of magmatic cycles with other geological events in the Turkestan–Alai region is based on data suggesting the Middle Carboniferous age of the following magmatic complexes distinguished in the southern Tien Shan:

monzodiorites and granodiorites of the Alai Mountains (Dubrov, 1940; Rezvoi, 1959, Kukhtikov, 1968; Dodonova *et al.*, 1984); basaltic lavas of the Kokshaal area (Brezhnev *et al.*, 1970); and a series of granitoid massifs occurring in the Nuratau, Turkestan, Alai, and Kokshaal ridges and ranging in age from 300 to 320 Ma according to available geochronological dates (Biske, 1996). The Middle Carboniferous age of intermediate to acidic dikes and volcanic rocks occurring in the Sb–Hg ore field of the southern Fergana is well correlative with the late Moscovian boundary level separating carbonate formations of the Alai type from the overlying Tolubai flysch–olistostrome complex. The "reversed" vertical succession of allochthonous ore deposits in the present-day thrust-and-fold structure of the study region (Belousov, 1995) can be interpreted as a result of rearrangement of the autochthonous Hg–Sb–Pb mineralization and formerly "normal" (lateral) metallogenic zoning in response to imbrication of thrust sheets.

Reorganization of lithospheric plates, orogenesis, and magmatism in mobile belts appear to be caused by activation of mantle plumes (Filatova, 1998) simultaneously disturbing those structural patterns of the mantle, which are responsible for generation and distribution of crustal ore-bearing fields (Kutina, 1982). Exactly these mantle processes should be considered by interpretation of the lateral metallogenic zoning in the crust (mercury–lead–tin from the south to the north), which was formed in the convergence zone between the Alai and Kyrgyz continents. In terms of geodynamic history, this zoning corresponded to the following structural elements reconstructed in the study region (in succession from the south to the north): Karachatyr sea and its ophiolite suture–Karachatyr plate–active margin of the Kyrgyz continent (Fig. 8).

The general features characterizing geodynamic evolution of mobile belts, which are recognizable in the geological history of the Turkestan–Alai region, are as follows: orogenesis lagged behind the folding phase (Artyushkov, 1993); simultaneous rising of fold mountains and downwarping of the adjacent foredeep in the rear zone of the continental plate subduction (Peive, 1980; Khain and Lomize, 1995); accelerated crustal subsidence in the foredeep at the moment of nappe thrusting (Khain and Lomize, 1995); migration of thrusting-related uplifts from the suture zone toward the foredeep (Mitchell and Garson, 1984) and formation of contrast relief forms at the time of olistostrome formation (Makarychev, 1989; Kukhtikov, 1993); and, finally, the plate movement polarity (Peive, 1980; Mitchell and Garson, 1984; Khain and Lomize, 1995). Also typical of the Turkestan–Alai region development are the regular arrangement of tectonic nappes in the regional structure and development of detachment planes prior to the continental accretion stage (Knipper, 1990).

New data on the island-arc affinity of the Lower–Middle Carboniferous basaltic lavas and volcanogenic terrigenous rocks bearing the redeposited fossils of the Namurian–Bashkirian age (Kichik-Alai, Sartale, Kan-i-Gut, and Turabulak localities) restrict their age range and suggest a wider, than accepted before, development of the Bashkirian volcanic activity in the region (Belousov, 1998). As far as it concerns the formation cycles of flysch–olistostrome formation, they were concurrent with two stages of continental subduction: the early stage corresponded to subduction of the Alai plate under the Karachatyr microcontinent (first cycle), and the later one was characterized by subduction of the amalgamated Alai–Karachatyr plate under the Kyrgyz continent (second cycle). The commencement of each cycle was marked by formation of carbonate allochthons (Tolubai and Maidan complexes), and their terminal phases corresponded to the emplacement time of thrust sheets into the foreland structures and accretionary terranes (Dzhidale and Sokh-Kyrgyzata complexes). Thus, considering the period of flysch accumulation in the foredeep, we can distinguish two subduction stages, two collision phases, and two cycles of sedimentation and nappe formation (Fig. 6, *2*; I–II and III–IV). One more problem concerns the geological nature of the South Fergana gravity maximum (Belousov, 1997b). The regional component of the maximum can be conditioned by the dome-like uplift of cold mantle material under the Turkestan ophiolite suture and also by wedging out of the dense continental crust at the passive margin of the Alai continent (Fig. 8). The local gravity component could be interrelated with the obducted slab of ultramafic rocks detectable at the depth of 10–15 km below the Alpine thrust-fault plane and Upper Paleozoic molasse beds.

CONCLUSION

Analyzing the present-day crustal section of the Alai Mountains, in other words, the vertical succession of formations, tectonic nappes, and allochthonous ore deposits, I reconstructed paleotectonic environments in the convergence zone between the Alai and Kyrgyz continents, where the lateral zoning of the Middle Carboniferous deposits bearing the autochthonous mineralization was recognized, and the incipient detachment faults of future thrust sheets were depicted. Reconstructing the paleotectonic cross-sections, I took into account the studied angular unconformities, principal structural elements of three continental plates, and manifestations of the subduction- and collision-related magmatism. In contrast to previous reconstructions, I distinguished for the first time the Karachatyr microcontinent and its collisional magmatic rocks. In addition, the formation mechanism of synsedimentary tectono-gravitational thrust sheets was considered more carefully.

The established correlation between different geological events, such as continental plate movements, their collision, cycles of magmatism and ore genesis, tectonic imbrication, folding, orogenesis, and foredeep

development, show that the Late Paleozoic subduction zone was inclined in the study region toward the north.

Reviewers A.S. Alekseev and V.E. Khain

REFERENCES

Artyushkov, E.V., *Fizicheskaya tektonika* (Physical Tectonics), Moscow: Nauka, 1993.

Banogin, S.N., New Data on Conglobreccia and Bauxites of Southern Fergana, *Geologiya i zakonomernosti razmeshcheniya nerudnykh poleznykh iskopaemykh Srednei Azii* (Geology and Distribution Pattern of Rock Products in Central Asia), Tashkent: Sred. Asiat. Inst. Geol. Mineral. Syr'ya, 1978, issue 1, pp. 20–36.

Belousov, V.I., Experience of Studying Metallogenic Tectonostratigraphy of the Alai and Other Thrust-and-Fold Structures, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1995, no. 5, pp. 3–12.

Belousov, V.I., Olistostrome and Thrust-Sheet Units in Flysch–Olistrostrome Complexes of the Turkestan–Alai Region, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1997a, no. 3, pp. 9–21.

Belousov, V.I., Geological Structure of the Alai Region Based on Data of Deep Vertical Electric Sounding, *Izv. Vyssh. Ucheb. Zaved., Geol. Razved*, 1997b, no. 4, pp. 3–14.

Belousov, V.I., Olistostromes and Nappes in Geoloogy of the Turkestan–Alai Region (Southern Tien Shan), Paper 2, *Izv. Vyssh. Uchebn. Zaved. Geol. Razved.*, 1998, no. 6, pp. 33–45.

Belousov, V.I. and Baer, M.A., Flysch–Olistostrome Formation of the Alai Mountains, *Izv. Vyssh. Uchebn. Zaved. Geol. Razv.*, 1989, no. 6, pp. 3–13.

Berger, V.I. and Natal'in, N.A., Facies Conditions of Antimony–Mercury Mineralization in the Southern Tien Shan, *Rudonosnost' osadochnykh kompleksov (Dokl. sovetsk. geologov na XXVIII sessii MGK)* (Ore-Bearing Potential of Sedimentary Complexes. Reports of Soviet Geologists to XXVIII Session of International Geological Congress), Leningrad: Vses. Geol. Inst., 1989, pp. 176–185.

Biske, Yu.S., *Paleozoiskaya struktura i istoriya Yuzhnogo Tyan'-Shanya* (Paleozoic Structure and History of the Southern Tien Shan), Petersburg: Leningrad. Gos. Univ., 1996.

Brezhnev, V.D., Dovzhikov, A.E., and Ivanov, G.V., Paleozoic Sediments in the Kokshaal System of Ridges, *Voprosy geologii Srednei Azii* (Problems of Geology of Central Asia), Leningrad: Vses. Geol. Inst., 1970, pp. 200–224.

Burtman, V.S., Southern Tien Shan, *Tektonicheskaya rassloennost' litosfery i regional'nye geologicheskie issledovaniya* (Tectonic Layering of the Lithosphere and Regional Geological Research), Moscow: Nauka, 1990, pp. 169–180.

Dodonova, T.A., Pomazkov, K.D., and Pomazkov, Ya.K., *Endogennye geologicheskie formatsii Kirgizii* (Endogenic Geological Formations of Kirgizia), Frunze: Ilim, 1984.

Dubrov, A.G., Arsenic Deposits in the Central Part of the Alai Ridge, *Geologiya i poleznye iskopaemye Srednei Azii* (Geology and Mineral Deposits of Central Asia), Moscow: Akad. Nauk SSSR, 1940, pp. 59–72.

Filatova, N.I., Cretaceous Evolution of Continental Margins as Related to Global Events, *Stratigr. Geol. Korrelyatsiya*, 1998, vol. 6, no. 2, pp. 3–17.

Gorzhevskii, D.I. and Donets, A.I., Geological–Genetic Typification of Lead–Zinc Deposits in Carbonate Complexes, *Rudonostnost' osadochnykh kompleksov (Dokl. sovetsk. geologov na XXVIII sessii MGK)* (Ore-Bearing Potential of Sedimentary Complexes. Reports of Soviet Geologists to XXVIII Session of International Geological Congress), Leningrad: Vses. Geol. Inst., 1989, pp. 153–161.

Khain, V.E. and Lomize, M.G., *Geotektonika s osnovami geodinamiki* (Geotectonics with Principles of Geodynamics), Moscow: Mosk. Gos. Univ., 1995.

Knipper, A.L., Tectonic Layering As a Natural Result of Evolution of the Earth's Crust in the Neogaea, *Tektonicheskaya rassloennost' litosfery i regional'nye geologicheskie issledovaniya* (Tectonic Layering of the Lithosphere and Regional Geological Research), Moscow: Nauka, 1990, pp. 5–12.

Konnov, L.P., *Geologiya i genezis boksitov Srednei Azii* (Geology and Genesis of Bauxites in Central Asia), Moscow: Nedra, 1972.

Kukhtikov, M.M., *Tektonicheskaya zonal'nost' i vazhneishie zakonomernosti stroeniya i razvitiya Gissaro-Alaya v paleozoe* (Tectonic Zones, Important Structural Features, and Development of the Hissar–Alai Region in the Paleozoic), Dushanbe: Donish, 1968.

Kurenkov, S.A., *Tektonika ofiolitovykh kompleksov Yuzhnogo Tyan'-Shanya* (Tectonics of Ophiolitic Complexes of the Southern Tien Shan), Moscow: Nauka, 1983.

Kurenkov, S.A., Perfil'ev, A.S., Pecherskii, D.M., *et al.*, Recurrent Spreading Events: Ophiolites of the Alai Ridge (Southern Tien Shan), *Vnutriplitnye yavleniya v zemnoi kore* (Intraplate Phenomena in the Earth's Crust), Moscow: Nauka, 1988, pp. 71–102.

Kutina, Ya., Possible Influence of Upper Mantle Structures on Distribution of Main Ore Deposits and Ore Fields, *Tezisy dokladov VI rudnogo simpoziuma* (Abstracts of Papers, VI Symposium on Mineralization), Tbilisi, 1982, pp. 138–139.

Lesnov, F.P., Belousov, V.I., Ageeva, L.I., and Vasil'ev, Yu.R., New Data on Geology and Peterology of the Sartale Polygenic Mafic–Ultramafic Pluton (Southern Tien Shan), *Giperbazitovye assotsiatsii skladchatykh oblastei* (Ultramafic Associations of Fold Areas), Novosibirsk: Inst. Geol. Geofiz., Sib. Otd. Akad. Nauk SSSR, 1982, pp. 26–57.

Makarychev, G.I., Ophiolitic Associations and Their Role in Tectonic Evolution of the Earth's Crust of the Southern Tien Shan, *Tektonicheskoe razvitie zemnoi kory i razlomy* (Tectonic Development of the Earth's Crust and the Faults), Moscow: Nauka, 1979, pp. 31–46.

Mitchell, A. and Garson, M., *Mineral Deposits and Global Tectonic Settings*, London: Academic Press, 1981. Translated under the title *Global'naya tektonicheskaya pozitsiya mineral'nykh mestorozhdenii*, Moscow: Mir, 1984.

Natal'in, N.A., Antimony and Mercury Ores of Subaerial Volcano-Sedimentary Origin (Examples from Southern Tien Shan), *Vulkanogenno-osadochnoe rudoobrazovanie. Tez. dokl.* (Volcano-Sedimentary Ore Genesis), Petersburg: Vses. Geol. Inst., 1992, pp. 100–101.

Nenakhov, V.M., Lytochkin, V.Yu., Perfil'ev, A.S., and Kuznetsov, L.V., Chaotic Complexes of the Paleozoic Structures in Southern Tien Shan, *Geologicheskoe kartirovanie khaoticheskikh kompleksov* (Geological Mapping of Chaotic Complexes), Moscow: Roskomnedra, 1992, pp. 8–85.

Pai, V.M., Geodynamics of Formation of the South-Alai Hummocking Zone, *Vestn. Mosk. Univ., Ser. 4: Geol.*, 1991, no. 4, pp. 29–40.

Peive, A.V., Zonenshain, L.P., Knipper, A.L., *et al.*, *Tektonika Severnoi Evrazii (Ob"yasnitel'naya zapiska k Tektonicheskoi karte Severnoi Evrazii m-ba 1 : 50000000* (Tectonics of Northern Eurasia: Explanatory Notes for Tectonic Map of Northern Eurasia, Scale 1 : 5000000), Moscow: Nauka, 1980.

Popov, V.I., Some Formational Regularities Concerning Origin and Distribution of Bauxite Deposits in Central Asia, *Geologiya, metody izucheniya i prognozirovaniya boksitov Srednei Azii* (Geology, Methods of Studying and Forecasting Bauxite Deposits in Central Asia), Tashkent: Sred. Aziat. Inst. Geol. Mineral. Syr'ya, 1972, pp. 7–14.

Popov, V.I., Zaprometov, V.Yu., and Shevchenko, O.D., Structural-Formational Zoning As a Basis of Forecast of Mineral Deposits (the Example of Geosynclinal Formations of Southern Fergana), *Geologiya i zakonomernosti razmeshcheniya nerudnykh poleznykh iskopaemykh Srednei Azii* (Geology and Distribution Pattern of Non-Metal Minerals of Central Asia), Tashkent: Sred. Aziat. Inst. Geol. Mineral. Syr'ya, issue 2, 1979, pp. 129–136.

Porshnyakov, G.S., *Gertsinidy Alaya i smezhnykh raionov Yuzhnogo Tyan'-Shanya* (Hercynides of the Alai Ridge and Adjacent Regions of Southern Tien Shan), Leningrad: Leningrad. Gos. Univ., 1973.

Rezvoi, D.P., *Tektonika vostochnoi chasti Turkestano-Alaiskoi gornoi sistemy* (Tectonics of the Eastern Part of the Turkestan-Alai Mountain System), L'vov: L'vov Univ., 1959.

Solov'eva, M.N., *Stratigrafiya i fuzulinidovye zony srednekamennougol'nykh otlozhenii Srednei Azii* (Stratigraphy and Fusulinid Zones in Middle Carboniferous Sediments of Central Asia), Moscow: Akad. Nauk SSSR, 1963.

Stratifitsirovannye i intruzivnye obrazovaniya Kirgizii (Stratified and Intrusive Formations of Kirgizia.), Frunze: Ilim, 1982, part 2.

Vanina, L.V., Tectonic Position of Lower Paleozoic Sediments in the Hercynides of the Southern Tien Shan (the Eastern Karachatyr and Adjacent Regions of the Alai Ridge as Examples), *Kaledonidy Tyan'-Shanya* (Caledonides of the Tien Shan), Frunze: Ilim, 1987, pp. 119–139.

Vanina, L.V., Early Paleozoic Geodynamics of the Southern Tien Shan, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1990, no. 8, pp. 113–122.

Voitovich, V.S., Paleotectonic Environments of Stratiform Deposits Formation, *Voprosy genezisa stratiformnykh mestorozhdenii tsvetnykh metallov* (Genetic Problems of Stratiform Deposits of Nonferrous Metals), Alma-Ata: Kaz. Inst. Mineral. Syr'ya, 1983, pp. 46–55.

Voitovich, V.S. and Donets, A.I., A Transition Tectonic Zone of Southern Fergana and Its Metallogeny, *Sov. Geol.*, 1985, no. 1, pp. 86–95.

Yagovkin, A.V., Hercynides of the Eastern Alai Ridge, *Extended Abstracts of Cand. Sci. (Geol.–Mineral.) Dissertation*, Leningrad: Leningrad. Gos. Univ., 1974.

Stratigraphy and Geological Correlation, Vol. 8, No. 5, 2000, pp. 526–527. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 5, 2000, pp. 111–112.
Original Russian Text Copyright © 2000 by Sokolov, Bublichenko, Zhamoida, Kagarmanov, Lobacheva, Rzhonsnitskaya.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Nikolai Lazarevich Bublichenko (1899–1999): A Centenary from the Hour of His Nativity

Nikolai Lazarevich Bublichenko, Doctor of Geology and Mineralogy, Professor, Corresponding Member of the Kazakhstan Academy of Sciences, and Honored Scientist was a distinguished explorer of the Kazakhstan geology, an eminent stratigrapher, paleontologist, and popularizer of geology.

He was born on October 9, 1899 (according to the Gregorian Calendar) in the family of doctors—Lazar Ivanovich, subsequently a distinguished researcher in medicine, and Evgeniya Yulianovna Bublichenko. In 1909, the family moved to Petersburg, where their son graduated college and entered the Geological Prospecting Faculty of the Mining Institute in 1916. When a student, he assisted the coal prospecting in Borovichi, worked together with I.I. Gorskii in the Urals and later in the Altai Mountains, and was a member of field team headed by I.F. Grigor'ev. The Altai trip had a pronounced effect on the life and scientific activity of Bublichenko. Since 1924 through all his years, he studied the Devonian and Carboniferous stratigraphy, brachiopod fauna, geology, tectonics, and mineral resources of the Altai Ore District.

At the time of student years, D.V. Nalivkin had an important influence with Bublichenko and guided his research work. It was under Nalivkin's leadership that Bublichenko had written the graduation paper *On Some Middle Devonian Brachiopods of Altai* (1928). The comprehensive study of these fossils and their correlation with the Eifelian fauna of Germany allowed him to substantiate the Middle Devonian age of brachiopods attributed earlier by G.G. Petts to the Early Devonian.

When graduated the Mining Institute, Bublichenko under the guidance of H. Stille in 1929 and then started his career as a member of the Geological Committee of the All-Union Council of the National Economy (VSNKh) and as researcher at the Central Institute of Geological Exploration for Base and Precious Metals (TsNIGRI) and All-Russia Research Institute of Geology (VSEGEI). These were institutions where he wrote his well-known works *Findings of the Coblencian Fauna in Kyrgyz Steppes* (1927) and *Brachiopod Fauna from the Lower Paleozoic Deposits in the Vicinity of the Village of Sarychumyshskaya, the Kuznetsk Basin* (1928), in which he showed himself as a profound researcher. He was the first in our country who applied the method of progressing grinding when studying the internal structure of brachiopods. In the work *The Early Devonian Brachiopod Fauna from the Vanch and Yazgulem River Basins (Western Pamirs)*, he pioneered in proving the presence of Lower Devonian deposits in the Pamirs.

Working for the Geological Committee, Bublichenko was at the head of geological survey and oil prospecting expeditions in the Minusinsk Depression and Cis-Urals regions. He has compiled the first geological map of the Lake Teletskoe area in the Altai Ore District and elucidated the origin of the lake. In 1936, he got his Candidate degree in Geological–Mineralogical Sciences without the official defense procedure.

In 1932–1936, Bublichenko directed a special expedition to the Karatau Ridge. The first geological map of the ridge was demonstrated in 1937 at the 17th Session of the International Geological Congress held in Moscow. Geological survey and prospecting work in the northern region adjacent to the Lake Balkhash was accompanied by the comprehensive study of stratigraphy and brachiopod fauna, and the results obtained were used as the basis for his Doctorate dissertation of 1939 that was entitled *Materials on Devonian Deposits of Northeastern Kazakhstan (Stratigraphy, Paleogeography, Fauna)*.

In 1940, Bublichenko went to Alma-Ata to join the Kazakh Branch of the USSR Academy of Sciences, and his activity was closely connected with the Altai Ore District since 1951. Beginning from 1958, he headed the Laboratory (Sector) of the Stratigraphy and Tectonics at the Altai Mining and Metallurgical Institute in Ust-Kamenogorsk, worked afterward as Director of the institute (1959–1963) later reorganized into the Altai Division of the Institute of Geological Sciences of the Academy of Sciences of the Kazakh Soviet Socialist Republic.

During many years of his work in Kazakhstan, Bublichenko created the basis for modern understanding of the geological structure and distribution of mineral resources in this commercially important region. In the mid-1930s, he submitted a paper on the tectonics of the Altai Ore District to a scientific session on the problems of general geology of the whole Altai region. In the paper, he presented the first tectonic scheme, where major thrust structures were distinguished and characterized. His works of 1940–1950s demolished data on the Carboniferous age of sedimentary sequences bearing some polymetallic ore deposits and proved their Devonian age. As early as in 1945, he argued for the stratigraphic control of polymetallic mineralization; later he distinguished three localization levels of ore minerals (Eifelian, Givetian, and Frasnian) in Devonian

volcanogenic–sedimentary deposits of the Altai Ore District. His ideas triggered a long-standing discussion on the genesis of polymetallic deposits of the Altai region, and the volcanogenic instead of hydrothermal origin of mineralization was finally recognized. Bublichenko was among those who headed and directly participated in exploration mapping of polymetallic deposits in the region as it is evident from his monograph *Principles and Methods of Predicting Chalcopyrite and Polymetallic Mineralization* (1972).

Particularly important is contribution of Bublichenko to stratigraphy and paleontology. Such a prominent work as *Paleontological Substantiation of Paleozoic Stratigraphy in the Altai Ore District* (1958) was accomplished under his guidance. He was first to elaborate the Devonian stratigraphic scheme for Kazakhstan and Altai; his exhaustive studies were used as a basis for creating unified stratigraphic schemes of Devonian deposits, and the regional stratigraphic units distinguished by him have not yet lost their importance. His major monographs devoted to brachiopods of Lower Carboniferous, Middle, and Upper Devonian deposits in the Altai Ore District (1971, 1974, 1976) have gained a wide recognition. He was editor, author and co-author of several fundamental works: *Geology of the USSR*, vol. 41; volume *Devonian System* of 1973 from the series *Stratigraphy of the USSR*; *State of Geological Examination of the USSR*, vol. 39. Bublichenko was an active member of the Devonian Commission of the Interdepartmental Stratigraphic Committee (ISC), Vice-Chairman of the Kazakh Regional ISC and Chairman of its Devonian Section; he actively participated in all principal international and domestic scientific conferences and meetings devoted to the Devonian and Carboniferous, delivering splendid presentations (in Prague, Leningrad, Minsk, etc.).

Bublichenko had many disciples; he taught at the Leningrad Technical School of Geological Prospecting and worked as Assistant Lecturer at the Mining Institute, as Professor at the Kazakh Mining–Metallurgical Institute and at Kazakh State University. He also supervised many postgraduate works.

His extensive and versatile activity was reflected in popularization of geological knowledge. He wrote articles for newspapers, delivered popular scientific lectures, and published the fascinating book *In Search For Natural Treasures of the Altai* (1974). In his archive, there is a manuscript, an essay full of love to the nature and devoted to the Lake Teletskoe. Another point of his keen interest was the Tarkhan Section, the unique nature of which he repeatedly described being entirely convinced that this is the unique natural monument. In total, Bublichenko published more than 150 works.

He was well educated personality having a wide range of interests and speaking English, German, French, and Czech. In the youth, the fate brought him many fascinating people. It happened so that B.M. Kustodiev, the fashionable painter, lived in the house which Bublichenko moved in with his family in 1909. A.M. Gorky, A.N. Benua, K.S. Petrov-Vodkin, M.L. Kropivnitskii (the Ukrainian actor and producer) and other famous peoples often visited the artist's apartment. The acquaintance with outstanding painters engendered in Bublichenko a profound love to the fine art. Portraits of young Nikolai and his father painted by B.M. Kustodiev are known world-wide.

Bublichenko was endowed with such personal qualities as culture, nobility, benevolence; he was a man of principle and unassuming manners, highly engrossed in science. His name has been put down to the Kazakhstan Gold Book of Honor on February 16, 1976. Bublichenko is eponym for several fossil species, e.g., for *Pedinocephalus bublichenkoi* Ivshin, 1959 (Cambrian trilobite from Kazakhstan); *Zmeinogorskia bublichenkoi* Spassky, 1960 (Middle Devonian anthozoan from Kazakhstan); and *Clarkeia bublichenkoi* Kaplun, 1968 (articulate brachiopod of the Upper Devonian from Kazakhstan).

B.S. Sokolov, G.N. Bublichenko, A.I. Zhamoida, A.Kh. Kagarmanov, S.V. Lobacheva, and M.A. Rzhonsnitskaya

PALEONTOLOGICAL JOURNAL

Editor-in-Chief
Leonid P. Tatarinov
Academician, Councellor of the Russian Academy of Sciences

Paleontological Journal (Paleontologicheskii Zhurnal) is the principal Russian periodical in paleontology. The journal publishes original work on the anatomy, morphology, and taxonomy of fossil organisms, as well as their distribution, ecology, origin, and evolution, and provides invaluable information on the biostratigraphy of Eastern Europe and Asia.

Paleontological journal indexed in *Georef.*

Scope:
- anatomy, morphology, and taxonomy of fossil organisms
- distribution, ecology, origin, and evolution of fossil organisms
- information on the biostratigraphy of Eastern Europe and Asia

2000 Volume 34 • ISSN 0031-0301
• Bimonthly + 3 Supplemental issues
$2075 US/Canada
$2390 Rest of World

Tel: 800-633-4931
205-995-1567 (outside US and Canada)
Fax: 205-995-1588

INTERPERIODICA
Subscription Office
P.O. Box 1831
Birmingham, AL 35201

Izvestiya, Physics of the Solid Earth

Editor-in-Chief
Vladimir A/ Magnitskii
Member of the Russian Academy of Sciences

Izvestiya, Physics of the Solid Earth (Fizika Zemli), founded in 1965, publishes results of original theoretical and experimental research in relevant areas of the physics of the earth's interior and applied geophysics. The journal presents results of studies conducted by researchers at institutes of the Russian Academy of Sciences and other institutions of the Russian Federation. Contributions from foreign authors are also welcome.

2000 Volume 36 • ISSN 1069-3513 • Monthly
$850 US/Canada
$940 Rest of World

Tel: 800-633-4931
205-995-1567 (outside US and Canada)
Fax: 205-995-1588

INTERPERIODICA
Subscription Office
P.O. Box 1831
Birmingham, AL 35201

Subscribe to the journals from the Russian Academy of Sciences

Translated and Published by MAIK "Nauka / Interperiodica"

(International Academic Publishing Company "Nauka / Interperiodica")

Distributed Worldwide by INTERPERIODICA

Copy this form to mail or fax your order today

	TITLE	Volume	ISSN	ISSUES	RATE IN US DOLLARS US/CAN	RATE IN US DOLLARS INTERNATIONAL	YOUR ORDER
❑	**Biophysics**	45	0006-3509	6	$2592	$2700	$ _____
❑	**Computational Mathematics and Mathematical Physics**	40	0965-5425	12	$2310	$2810	$ _____
❑	**Doklady Earth Sciences**	370-375A	1028-334X	9	$2905	$3340	$ _____
❑	**Doklady Mathematics**	61-62	1064-5624	6	$1395	$1600	$ _____
❑	**Entomological Review**	80	0013-8738	9 + 2 Suppl.	$2635	$3030	$ _____
❑	**Environmental Geoscience**	3	Pending	4	$610	$690	$ _____
❑	**Eurasian Soil Science**	33	1064-2293	12 + 2 Suppl.	$2390	$2750	$ _____
❑	**Geochemistry International**	38	0016-7029	12 + 3 Suppl.	$2890	$3320	$ _____
❑	**Geology of Ore Deposits**	42	1075-7015	6	$980	$1125	$ _____
❑	**Geomagnetism and Aeronomy**	39	0016-7932	6	$675	$775	$ _____
❑	**Geomagnetism and Aeronomy**	40	0016-7932	6	$745	$855	$ _____
❑	**Geotectonics**	34	0016-8521	6	$580	$630	$ _____
❑	**Herald of the Russian Academy of Sciences**	70	1019-3316	6	$1410	$1790	$ _____
❑	**Izvestiya. Atmospheric and Oceanic Physics**	36	0001-4338	6	$810	$870	$ _____
❑	**Izvestiya, Physics of the Solid Earth**	36	1069-3513	12	$850	$940	$ _____
❑	**Journal of Communications Technology and Electronics**	45	1064-2269	12 + 2 Suppl.	$3115	$3585	$ _____
❑	**Journal of Computer and Systems Sciences International**	39	1064-2307	6	$2100	$2420	$ _____
❑	**Journal of Ichthyology**	40	0032-9452	9 + 2 Suppl.	$2265	$2605	$ _____
❑	**Laser Physics**	10	1054-660X	6	$1130	$1365	$ _____
❑	**Oceanology**	40	0001-4370	6	$720	$775	$ _____
❑	**Paleontological Journal**	34	0031-0301	6 + 3 Suppl.	$2075	$2390	$ _____
❑	**Pattern Recognition & Image Analysis**	10	1054-6618	4	$700	$800	$ _____
❑	**Petroleum Chemistry**	40	0965-5441	6	$2840	$2950	$ _____
❑	**Petrology**	8	0869-5911	6	$980	$1125	$ _____
❑	**The Physics of Metals and Metallography**	89-90	0031-918X	12 + 2 Suppl.	$2770	$3190	$ _____
❑	**Physics of Particles and Nuclei**	31	1063-7796	6	$1965	$2085	$ _____
❑	**Polymer Science. Series A**	42	0965-545X	12	$2630	$3030	$ _____
❑	**Polymer Science. Series B**	42	1560-0904	6	$1000	$1150	$ _____
❑	**Polymer Science. Series C**	42	Pending	2	$350	$400	$ _____
	Series A + B + C discount 20%				$3180	$3680	$ _____
❑	**Proceedings of the Steklov Institute of Mathematics**	228-231	0081-5438	4 + 2 Suppl.	$1405	$1620	$ _____
❑	**Russian Journal of Inorganic Chemistry**	45	0036-0236	12 + 3 Suppl.	$3405	$3915	$ _____
❑	**Russian Journal of Mathematical Physics**	7	1061-9208	4	$570	$650	$ _____
❑	**Russian Journal of Physical Chemistry**	74	0036-0244	12 + 3 Suppl.	$3405	$3915	$ _____
❑	**Stratigraphy and Geological Correlation**	8	0869-5938	6	$980	$1125	$ _____
❑	**Studies on Russian Economic Development**	11	1075-7007	6	$715	$820	$ _____
❑	**Thermal Engineering**	47	0040-6015	12	$1530	$1760	$ _____
❑	**Thermophysics and Aeromechanics (only distribution)**	7	0869-8643	4	$650	$780	$ _____
						TOTAL	_____

❶ Name _____
Institution _____
Address _____
_____ State _____
City _____ Country _____
Zip/Postal Code _____
Telephone (_____)

Delivery is not made until payment is received

To order by phone call **1 800 633-4931**
or (205) 995-1567 outside the US and Canada

❷ ❑ My payment for $_____ is enclosed.
OR
❑ Bill me. My library's purchase order number is _____

❸ Send this order and payment to:
INTERPERIODICA
P.O. Box 1831
Birmingham, AL 35201-1831
Or fax this order form to (205) 995-1588

Order now for immediate delivery. All journals will be published in 2000!

MAIK "Nauka/Interperiodica" Publishing

is pleased to present to the international scientific community simultaneous Russian- and English-language publication of the journals of the Russian Academy of Sciences

International Academic Publishing Company "Nauka/Interperiodica" (MAIK "Nauka/Interperiodica"), in cooperation with the Russian Academy of Sciences, publishes the results of research in all fields of modern science performed by leading scientists and scientific institutions from Russia, the CIS, and other countries. Simultaneous English translation of the journals is provided by Interperiodica Publishing, the translation division of MAIK "Nauka/Interperiodica". Today, scientists around the world have direct access to the most significant Russian research at the time it is first published in Moscow – at the time it is most relevant to the worldwide scientific community. In addition to more timely publication, readers benefit from more precise translations of each journal, provided by a carefully chosen team of scientific translators with direct access to the authors and editors. English versions of the journals published by MAIK "Nauka/Interperiodica" are distributed worldwide by Interperiodica, Kluwer Academic/Plenum Publishers, and the American Institute of Physics.

MAIK "Nauka/Interperiodica" 2000 volumes include the following titles:

- *Biophysics*
- *Computational Mathematics and Mathematical Physics*
- *Doklady Earth Sciences*
- *Doklady Mathematics*
- *Entomological Review*
- *Environmental Geoscience*
- *Eurasian Soil Science*
- *Geochemistry International*
- *Geology of Ore Deposits*
- *Geomagnetism and Aeronomy*
- *Geotectonics*
- *Herald of the Russian Academy of Sciences*
- *Izvestiya, Atmospheric and Oceanic Physics*
- *Izvestiya, Physics of the Solid Earth*
- *Journal of Communications Technology and Electronics*
- *Journal of Computer and Systems Sciences International*
- *Journal of Ichthyology*
- *Journal of Journals*
- *Laser Physics*
- *Oceanology*
- *Paleontological Journal*
- *Pattern Recognition and Image Analysis*
- *Petroleum Chemistry*
- *Petrology*
- *Polymer Science, Series A*
- *Polymer Science, Series B*
- *Polymer Science, Series C*
- *Physics of Particles and Nuclei*
- *Proceedings of the Steklov Institute of Mathematics*
- *Russian Journal of Inorganic Chemistry*
- *Russian Journal of Mathematical Physics*
- *Russian Journal of Physical Chemistry*
- *Stratigraphy and Geological Correlation*
- *Studies on Russian Economic Development*
- *The Physics of Metals and Metallography*
- *Thermal Engineering*
- *Thermophysics and Aeromechanics**

* *Thermophysics and Aeromechanics* is only distributed by MAIK "Nauka/Interperiodica" Publishing

Please direct all inquiries about the above journals to: **INTERPERIODICA**, P.O. Box 1831, Birmingham, AL 35201-1831.
For faster service call toll-free (800) 633-4931 or (205) 995-1567 (outside US and Canada). Fax: (205) 995-1588, E-mail: interperiodica@ebsco.com

- *Applied Biochemistry and Microbiology*
- *Automation and Remote Control*
- *Biochemistry (Moscow)*
- *Biology Bulletin*
- *Colloid Journal*
- *Cosmic Research*
- *Differential Equations*
- *Doklady Biochemistry*
- *Doklady Biological Sciences*
- *Doklady Biophysics*
- *Doklady Botanical Sciences*
- *Doklady Chemical Technology*
- *Doklady Chemistry*
- *Doklady Physical Chemistry*
- *Glass Physics and Chemistry*
- *High Energy Chemistry*
- *High Temperature*
- *Human Physiology*
- *Inorganic Materials*
- *Instruments and Experimental Techniques*
- *Journal of Analytical Chemistry*
- *Journal of Evolutionary Biochemistry and Physiology*
- *Kinetics and Catalysis*
- *Lithology and Mineral Resources*
- *Microbiology*
- *Molecular Biology*
- *Problems of Information Transmission*
- *Programming and Computer Software*
- *Protection of Metals*
- *Radiochemistry*
- *Russian Journal of Applied Chemistry*
- *Russian Journal of Bioorganic Chemistry*
- *Russian Journal of Coordination Chemistry*
- *Russian Journal of Developmental Biology*
- *Russian Journal of Ecology*
- *Russian Journal of Electrochemistry*
- *Russian Journal of General Chemistry*
- *Russian Journal of Genetics*
- *Russian Journal of Marine Biology*
- *Russian Journal of Nondestructive Testing*
- *Russian Journal of Organic Chemistry*
- *Russian Journal of Plant Physiology*
- *Russian Microelectronics*
- *Solar System Research*
- *Theoretical Foundations of Chemical Engineering*
- *Water Resources*

Please direct all inquiries about the above journals to: **Kluwer Academic/Plenum Publishers**, 233 Spring Street, New York, NY 10013. Phone: (212) 620-8467. Fax: (212) 807-1047, E-mail: journals@plenum.com

- *Acoustical Physics*
- *Astronomy Letters*
- *Astronomy Reports*
- *Crystallography Reports*
- *Doklady Physics*
- *JETP Letters*
- *Journal of Experimental and Theoretical Physics*
- *Optics and Spectroscopy**
- *Physics of Atomic Nuclei*
- *Physics of the Solid State*
- *Plasma Physics Reports*
- *Semiconductors*
- *Technical Physics*
- *Technical Physics Letters*

Please direct all inquiries about the above journals to: **American Institute of Physics**, Circulation and Fulfillment Services, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502 USA. Tel. (516) 576-2270, 1-800-344-6902. Fax: (516) 349-9704, E-mail: subs@aip.org

**Optics and Spectroscopy*: Optical Society of America, 2010 Massachusetts Ave., NW, Washington, DC 20036-1023, Attn.: Publications Department. Tel. (202) 223-8130, (800) 582-0416. Fax: (202) 223-1096.

International Academic Publishing Company "Nauka/Interperiodica" (MAIK "Nauka/Interperiodica")
Profsoyuznaya ul., 90, Moscow, 117864, Russia, Phone: 7 (095) 3361600; Fax: 7 (095) 336 0666,
E-mail:compmg@maik.rssi.ru, http://www.maik.rssi.ru